Aquatic, Riparian, and Wetland Ecosystem Assessment
Bighorn National Forest, Wyoming
USDA Forest Service - Rocky Mountain Region

Report 1 of 3

Introduction and Ecological Driver Analysis

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The Bighorn Aquatic, Riparian and Wetland Ecosystem Assessment is presented in three separate reports. The reports can be cited as follows:

Winters, D.S. et al. 2004. Aquatic, Riparian and Wetland Ecosystem Assessment for the Bighorn National Forest. Report 1 of 3. Introduction and Ecological Driver Analysis. Denver: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region.

Winters, D.S. et al. 2004. Aquatic, Riparian and Wetland Ecosystem Assessment for the Bighorn National Forest. Report 2 of 3. Anthropogenic Influences Report. Denver: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region.

Winters, D.S. et al. 2004. Aquatic, Riparian and Wetland Ecosystem Assessment for the Bighorn National Forest. Report 3 of 3. Ecological Driver Analysis and Anthropogenic Influence Results: Synthesis and Discussion. Denver: U.S. Department of Agriculture, Forest Service, Rocky Mountain Region.

EXECUTIVE SUMMARY

This ecological assessment is the product of a cooperative effort by the USDA Forest Service and scientists from Colorado State University and the University of Wyoming. A synthesis of the best available information about aquatic, riparian, and wetland ecosystems associated with the Bighorn National Forest (BNF), and the anthropogenic influences from Euro-American settlers and more recent human activities on these resources is documented.

The assessment responds to direction from the Regional Leadership Team of the USDA Forest Service Rocky Mountain Region (Region 2) to improve the quality and consistency of forest and project planning, and overall resource management. The Leadership Team recognized that this was a difficult task given the numerous laws and directives the USFS follows and the complexity of resource management related to species viability and ecosystem integrity. As a result, the Region 2 Species Conservation Team, consisting of ecologists, botanists, and biologists, were charged with developing and implementing a process to address species conservation and ecological sustainability. This ecosystem assessment is the component of the Species Conservation Project that focuses on the ecological characteristics, influences, and condition of aquatic, riparian, and wetland resources on the BNF.

The development of a classification scheme, which provides an understanding of the sensitivity, abundance, and unique characteristics of aquatic, riparian, and wetland ecosystems within the BNF, the surrounding landscape, and across Region 2, is defined in this assessment. The assessment includes an analysis, which classifies small watersheds into distinct groups that differ in aquatic, riparian, and wetland resource productivity, abundance, and response to disturbance. This "ecological driver" concept provides a sound stratification of aquatic, riparian, and wetland resources in the Bighorn landscape as well as potentially across Region 2. A total of 24 historic and current anthropogenic influences were also analyzed in a rigorous and regionally consistent manner. Such analysis promotes consistent and efficient comparisons of influences between watersheds within a forest, among several forests, and among multiple land ownerships. A synthesis of ecological drivers and anthropogenic influences was also conducted to assess the sensitivity, importance, and management risks associated with aquatic, riparian, and wetland resources. These analyses will be valuable to help identify priority areas for restoration and monitoring, as well as development of reference conditions, program development, and refinement of management direction.

At the request of the Species Conservation Steering Committee and BNF staff, key management implications for these sensitive aquatic resources are discussed. However, specific decisions concerning management of any lands within the BNF or future management needs are not presented. Instead, the document and its conclusions should stimulate interdisciplinary discussion, enhance future analysis and monitoring efforts, and clarify resource management, and restoration opportunities.

The data used for this assessment will not only be distributed to the BNF, but also incorporated into a regional and national database for future comparisons among administrative units. Therefore this assessment provides a solid foundation of data related to aquatic, riparian, and wetland resources for all BNF employees to use that will improve consistency in data collection and management focus in the future. The BNF Aquatic, Riparian and Wetland Assessment is presented in three separate reports: Report 1: Introduction and Ecological Driver Analysis; Report 2: Anthropogenic Influences Report; and Report 3: Ecological Driver Analysis and Anthropogenic Influence Results: Synthesis and Discussion.

Finally, the assessment results will support more effective, efficient, and consistent watershed assessments and cumulative effects analysis on the BNF and throughout Region 2. We believe that this assessment provides a common scientific foundation that the BNF and other agencies such as the Wyoming Game and Fish Department can rely on for future management and planning activities. Through this effort, Region 2 and university scientists have developed a valuable partnership that will continue to pursue meaningful ecosystem studies to address key management issues throughout Region 2.

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Chapter 1
Introduction

This report describes a multiple scale aquatic, riparian, and wetland ecosystem assessment for the Bighorn National Forest in northern Wyoming. This Forest includes approximately 1.1 million acres of the 22 million acres of National Forests and National Grasslands in the Rocky Mountain Region (Region 2) of the USDA Forest Service.

The Forest is located in the Big Horn Mountains of the Upper Missouri River Basin (fig. 1.1), with about 99 percent of the Forest exceeding one mile (5,280 ft or 1,600 m) in elevation (fig. 1.2).

Key Findings

1. The BNF comprises only 1.1% of the upper Missouri River Basin, with only 15% of the Basin located above 5,280 feet.
2. The BNF comprises approximately 16% of the area within the surrounding landscape scale, with less than 35% of the area at this scale above 5,280 feet.
3. Sensitive aquatic, riparian, and wetland resources, which are not commonly found throughout the upper Missouri River Basin, are found within the BNF.
4. There are 248, 6th level hydrologic unit boundaries (HUBs) at the landscape scale of this assessment. Only 17 HUBs are entirely within the BNF boundary. Therefore the management influence is important in a relatively small subset of HUBs.

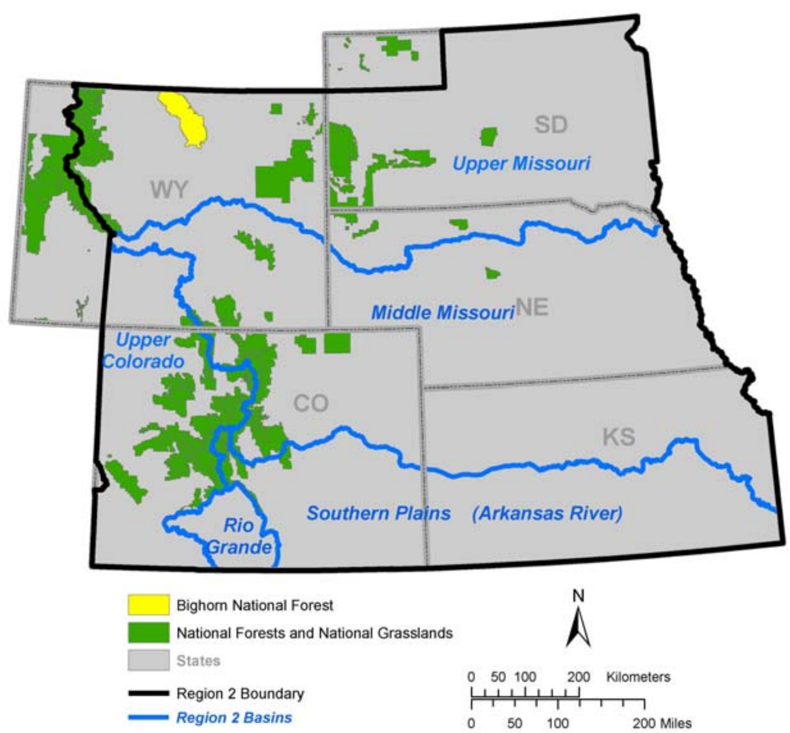


Figure 1.1. Region 2 of the USDA Forest Service with National Forests, National Grasslands, and major river basins identified.

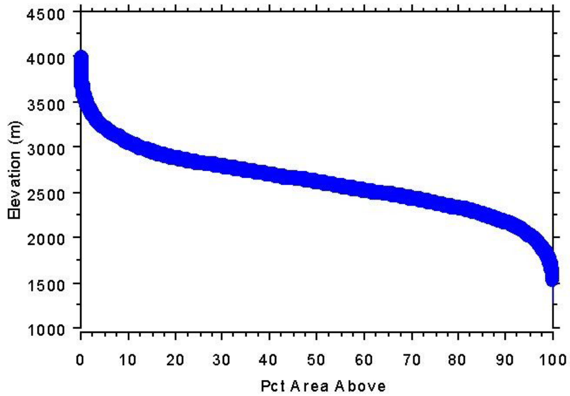


Figure 1.2. The hypsometric curve graphically displays the percentage of land surface area above, given elevations of the Bighorn National Forest.

The Aquatic, Riparian, and Wetland Assessment Process

The aquatic, riparian, wetland assessment process is part of the Region 2 Species Conservation Project (SCP). The overall goal of this project is to enhance the scientific credibility and legal defensibility of forest plans and project actions in their efforts to conserve the viability of at-risk species and sustain the health of their ecosystems. The SCP consists of species assessments and ecosystem assessments. The primary goal of the s*pecies assessments* is to describe the biology, ecology, and conservation needs of identified species or taxa. The main goal of the aquatic, riparian, and wetland e*cosystem assessments* are to portray historic and current conditions of terrestrial habitats, and aquatic, riparian, and wetland habitats and the effects of natural and human disturbances. Results of the two types of assessments can be combined to show species-ecosystem relationships and improve conservation efforts (fig. 1.3).

Region 2 spans a vast diversity of ecosystems ranging from alpine tundra, mountain forests, foothill woodlands, to plains grasslands. Many administrative units cross broad ecosystems and river basins. A primary objective of the SCP is to analyze species viability and ecosystem health for ecological units in order to create a consistent framework for ecological conservation applicable across administrative units.

This assessment is the first of its type to be done in Region 2. This Bighorn pilot effort has yielded two key products: 1) an *assessment protocol* to guide ecosystem assessments in other Forests (Winters et al. 2003a and b), and 2) the *ecosystem assessments* for the Bighorn ecosystem. As part of the adaptive process identified in Winters et al. (2003a), the Bighorn assessment is a prototype that will improve the quality of the protocols for future assessments. Validation studies are being conducted to test the assumptions associated with this assessment.

Assessment Goals and Objectives

In general, ecosystem assessments are conducted in order to portray historic and current ecosystem conditions and the effects of natural and human disturbances. The Bighorn aquatic, riparian, and wetland assessment is specifically organized to answer detailed questions about the ecological environment, natural disturbance regimes and ecosystem dynamics, effects of human disturbances, assessment limitations and data gaps, and inventory and monitoring principles. The explicit goal is to give the Forest solid information that will enhance the analysis of ecological effects, the effectiveness of conservation efforts, and the design of future studies. The main objectives are to identify critical resource values for which we need to manage, degraded or threatened resources we need to restore, and where to act first. A list of specific questions that are answered by this assessment include:

(1) What are the keystone ecosystem elements (e.g., geology, climate, landform, etc.) that influence the form and function of aquatic, riparian, and wetland ecosystems?
(2) What are the physical, biological, and ecological characteristics and trends of the current environment?
(3) What and where are the watersheds with important and unique aquatic, riparian, and wetland characteristics? And how do they relate to the surrounding landscape?
(4) How have exotic plants and animals influenced ecological integrity of aquatic,

riparian, and wetland species (e.g., introduction of non-native fishes)?

(5) What anthropogenic factors individually and cumulatively have altered aquatic, riparian, and wetland ecosystems?

(6) Where do we expect the highest risk from future management activities?

(7) What are the limits in application and interpretation of the assessments?

(8) What major information gaps are revealed by the assessments?

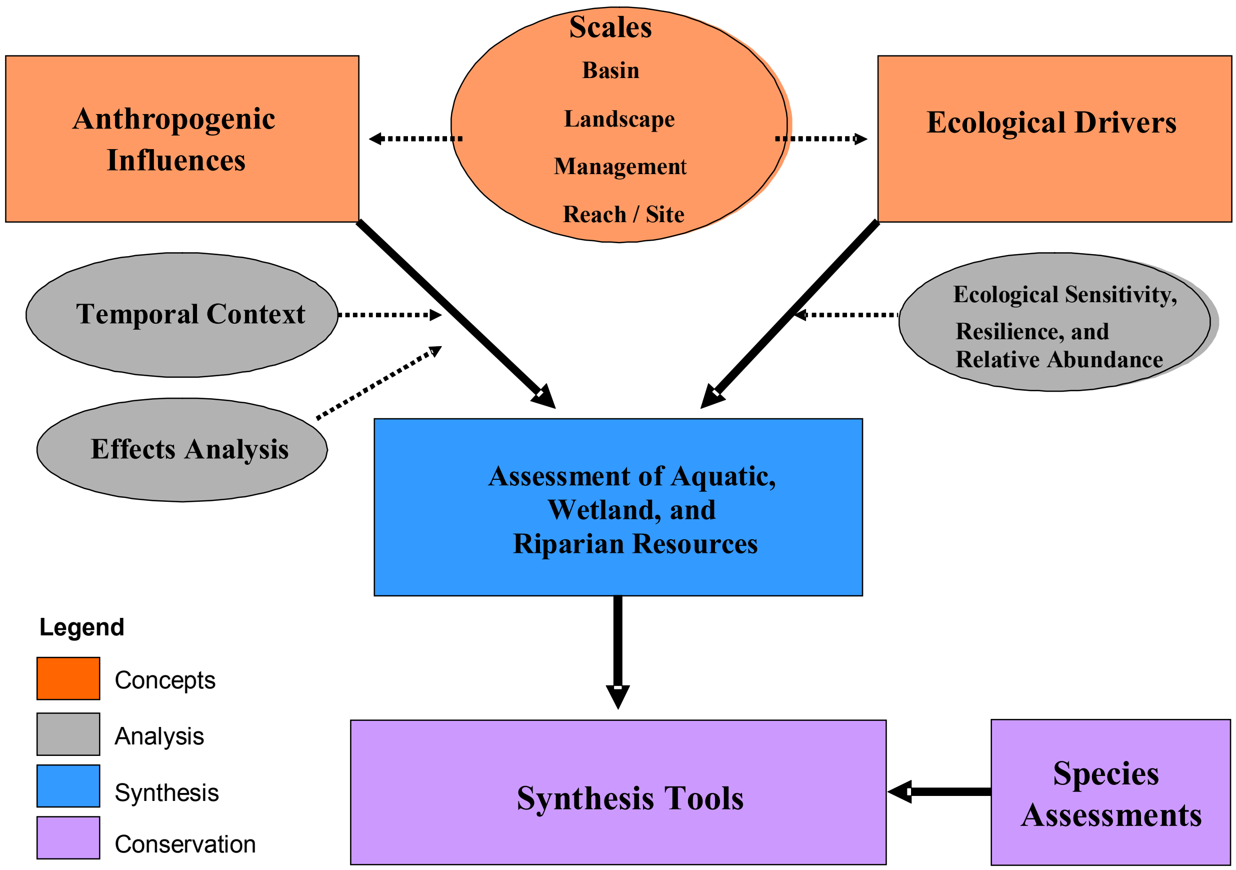


Figure 1.3. Flowchart showing the conceptual model of the aquatic, riparian, and wetland assessment process.

Relationship to Forest Planning

The National Forest Management Act (NFMA) of 1976 (P.L. 94-588, 90 Stat 2949, as amended) provides the basis for conducting broad scale ecological assessments. The NFMA states that the Forest Service is responsible to "provide for diversity of plant and animal communities based on the suitability and capability of the specific land area in order to meet overall multiple-use objectives." In addition, "fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area."

We must understand the natural processes and human influences that shape ecological systems in order to comply with this direction. Multiple scale ecological assessments provide the spatial and temporal information needed to understand ecological form and function and equip land managers to select sound conservation actions. Ecological assessments are not decision documents because they do not resolve issues nor solve policy questions (Jensen et al. 2001). What a multiple scale ecological assessment *should* do is:

(1) Synthesize existing information and present conclusions about the status, trends, spatial patterns, and relationships of ecosystems and species; and
(2) Identify relationships between human land use, species viability, ecosystem health, and disturbance processes as well as the biophysical capabilities of the landscape.

In order to meet this challenge, the SCP team developed a process to feed ecological information into forest and project planning in order to enhance species and ecosystem conservation (fig. 1.4). Species assessments and ecosystem assessments are being conducted and then blended using 'synthesis tools" that show species-ecosystem tradeoffs. Forests can use these tools to consistently analyze ecological effects and design effective conservation alternatives.

The aquatic, riparian, and wetland assessment for the Bighorn National Forest ecosystem can provide valuable information for the Forest Plan revision process, including to:

(1) Summarize existing condition information, including databases for further analysis.
(2) Identify important and unique aquatic, riparian, and wetland resources that may influence alternative development.
(3) Identify risks and sensitivity of watersheds for alternative development.
(4) Provide important habitat distribution information for monitoring management indicator species.
(5) Identification of prescription areas for rare and/or important aquatic, riparian, and wetland resources.

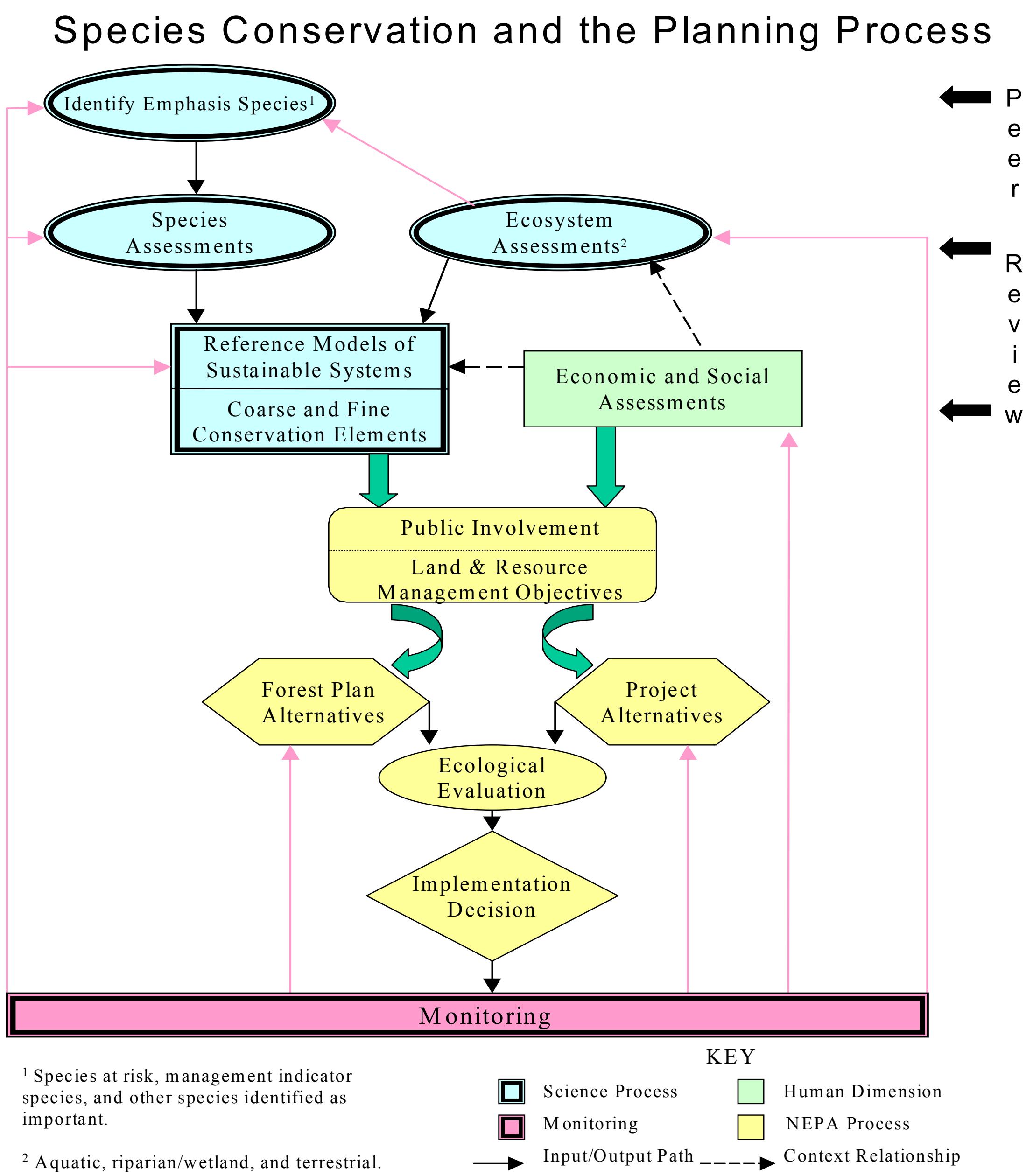
In contrast, this aquatic, riparian, and wetland assessment cannot:

(1) Quantify the condition of communities of plants, animals or their habitats.
(2) Identify thresholds for impacts.
(3) Provide results to identify site level standards and guidelines.

Relationship to Program and Project Development

The term "Program" in the context of USDA Forest Service management refers to a long term strategic planning effort for a particular resource area, such as fisheries, hydrology or Threatened and Endangered Species. Budgets are developed continually over a several year period, as are accomplishment expectations. In order to meet expectations of accountability and meet the needs of the public and resources over a relatively large landscape, priorities for management must be made. These priorities often involve funding and resources from other agencies and public groups. Projects are implemented through program developed. Resource specialists participate in projects through development within their program area or support to other program areas. The Bighorn Aquatic, Riparian, and Wetland Assessment can help in this program by:

(1) Identifying the highest priority watersheds for reintroduction of native but extirpated species.
(2) Identifying watersheds with similar ecological condition so site-specific reference conditions and subsequent levels of impacts can be quantified through monitoring.
(3) Identifying the relative impacts to important areas like municipal watersheds, native species watersheds, and important wetland/riparian areas for restoration.
(4) Developing multiple year projects and funding needs at the watershed scale.
(5) Identifying the risk, sensitivity, and abundance of aquatic, riparian, and wetland resources for analysis for other program area projects.



¹ Species at risk, management indicator species, and other species identified as important.

² Aquatic, riparian/wetland, and terrestrial.

Figure 1.4. Conceptual model for the Species Conservation Project.

Ecological Scales

Multiple scales must be addressed in order to ecologically assess aquatic, riparian, and wetland resources (Frissell et al. 1986). Both upslope and upstream processes affect all aquatic, riparian, and wetland ecosystems (Wohl 2001), so they present a unique challenge for multi-scaled analysis. The aquatic, riparian, and wetland assessment is conducted in a nested hierarchy of hydrologic units (Maxwell et al. 1995). Factors that prevail at coarser scales constrain the form and function of aquatic, riparian, and wetland ecosystems at finer scales.

The four spatial scales used, for the Bighorn aquatic, riparian, and wetland assessment, are basin, landscape, management, and reach/site scales. These scales correspond to watershed delineations adopted by the USDA Forest Service (Maxwell et al. 1995). Reach and site scale information are not analyzed in this assessment. Instead, a list of specific questions to be addressed at the reach/site scale is presented based on results of the higher-scale analyses.

A more thorough description of the development and importance of these scales are presented in Winters et al 2003a, and in Chapter 2 of this report.

Aquatic, Riparian, and Wetland Ecological Context of the Bighorn National Forest

The Bighorn National Forest assessment area is within the Arctic-Atlantic Sub-zone, the Mississippi Region and Sub-region, and the Upper Missouri River Basin (table 1.1).

Table 1.1. Ecological context of Bighorn National Forest Assessment area.

Scale	Category	Name
Larger	Sub-zone	Arctic-Atlantic
↓	Region	Mississippi
Smaller	Sub-region or Basin	Upper Missouri

The Arctic-Atlantic Sub-zone contains all streams draining into the Gulf of Alaska, the Arctic and Atlantic Oceans, and the Gulf of Mexico down to the Rio Grande system. It is one of three North American sub-zones created mostly by plate tectonics and mountain building. Eastern and western North America have independent faunal histories since the Rocky Mountains were uplifted (Gilbert 1976). Arctic-Atlantic fish fauna are more widely distributed than, and differ sharply from, the Pacific Sub-zone (Mayden 1992).

The Mississippi Region contains all streams draining into the Gulf of Mexico between the Florida peninsula and the Rio Grande system. It is one of six Arctic-Atlantic regions created mostly by glaciation and regional uplift. The Mississippi Region reflects mergers and separations of fishes caused by Pleistocene glaciation and mountain-building processes.

The Upper Missouri River Basin is one of 15 Mississippi Sub-regions whose geomorphic history caused mixing and isolation of fish species. The Missouri River flowed north into the Hudson River system in Pliocene times, was joined to the Mississippi River system by Pleistocene glaciation, and exhibits unique faunal elements as a result. The Upper Missouri River Basin has a unique mixture of native fauna in both its coldwater and warmwater systems.

The Bighorn National Forest is in an isolated mountain mass surrounded by plains and comprises only 0.06 percent of the land area in the Upper Missouri River Basin. The seven sub-basins within the Bighorn National Forest drain the Big Horn Mountains in all directions into the Big Horn, Tongue, and Powder River systems. Most of the aquatic ecosystems are coldwater systems. The terrestrial ecosystems in the Forest range from alpine tundra and rocky lands to mixed conifer and aspen forests interspersed with mountain meadows.

Physiographic Context of the Bighorn National Forest

The Big Horn Mountains are physiographically distinct from much of the Upper Missouri River Basin. High plains constitute a large proportion of the basin, with over 50% of the surface area lying below 3,300 ft (1,000 m) (fig. 1.6.) The elevations within the Big Horn Mountains, within the National

Forest boundary, range from 4,200 to 13,167 ft (1,500 to 4,000 m). About 99 percent of the Forest is higher than 5,280 ft (1,600 m), and 90 percent is higher than 6,500 ft (2,150 m).

The Bighorn National Forest can be segregated into four categories of landform types. At the lower elevations, the landscape has rolling plains. Above the plains, the surface rises steeply to a maturely dissected plateau. This steeply sloping portion of the Forest contains hogback and flatiron formations on the eastern and western flanks of the mountain range. Rising above the high plateau are dramatic, glacial-sculpted peaks, reaching a maximum elevation of 13,167 ft on the summit of Cloud Peak.

The Big Horn Mountains have been subjected to several episodes of glaciation during the Pleistocene. The glacial activity was concentrated around the Cloud Peak area of the Forest, and moraine deposits can be found as low as approximately 6,500 ft (Darton 1906). This glacial activity carved broad, u-shaped valleys where cirques, tarns, several wetland types (including fens, bogs, and marshes), and low gradient streams are common (fig. 1.5). Narrow, steep-sided valleys containing moderate- to high-gradient streams characterize the unglaciated areas.

Figure 1.5. Photo of a glaciated valley with a low gradient stream and wetlands in the Bighorn National Forest.

Ecological Drivers

Geology, glacial history, climate or precipitation regime, flow regime and stream gradient determine the natural form and function of aquatic, riparian, and wetland ecosystems. These *ecological drivers* control physical features such as land slope and aspect, stream form and gradient, thermal and moisture regimes, soil depth and fertility, and stream substrate and chemistry that constrain biological composition and processes.

Combinations of ecological drivers are analyzed to provide information on the landscape structure, which may be conducive to the presence and abundance of aquatic, riparian, and wetland resources. This assessment builds a *matrix* of ecological driver combinations and conducts a *cluster analysis*, which provides a statistical means of grouping watersheds with similar driver combinations. Cluster results are subsequently analyzed for crucial ecological components such as trout or wetland abundance and the sensitivity of aquatic, riparian, and wetland ecosystems to human influences such as sedimentation from roads or tree cutting. Chapter 2 presents these analyses.

Validation of the ecological driver analysis is a key step in the assessment process, and field data are being collected in the Bighorn landscape to test the accuracy of the predictions. Preliminary data show strong and significant correlation between ecological driver predictions and actual field conditions, thus validating the framework and ecological driver analysis for the Bighorn National Forest. On each Forest, aquatic, riparian, and wetland assessments should include validation studies to verify local predictions.

Human History

Archeological records of people in the region go back to at least 8,300 years before present, when hunter-gatherers occupied the Bighorn Basin. By AD 1500, Native Americans of the Shoshone, Sioux, Crow, Arapaho, and Cheyenne tribes occupied the region. The medicine wheel on Medicine Bow Mountain, which is at least 250 years old, is attributed to either the Shoshone or the Crow.

Francois and Louis-Joseph Verendrye, who crossed the mountains near Sheridan in 1743, are the first Europeans known to have reached the Bighorns. In 1811 Wilson Price Hunt's Astorian expedition of fur trappers traveled up the Missouri River and crossed the Bighorns, and Jedediah Smith led another group of trappers over the mountains circa 1822. Between 1820 and 1840 fur trappers and missionaries gradually explored the region. Euro-American presence in the region increased dramatically with the start of emigration west along the Oregon Trail in 1843. Congress passed the Homestead Act in 1862, and Jim Bridger developed a trail over the Bighorns for incoming settlers in 1864. Three years later the Union Pacific railroad reached Cheyenne; in 1868 Wyoming became a territory; and in 1872 Congress declared Yellowstone a national park (Smith 1992; Moulton 1995). All of these activities facilitated Euro-American travel to these areas and encouraged settlement in the region.

In 1878, the first ranch near the Big Horn Mountains was developed in the Big Horn Basin. This resulted in the first ditch diverting surface water from adjacent streams. Within a year, nearly every watercourse in the region had ditches, and the irrigation network grew rapidly over the next ten years (Mead 1899). Mormon irrigators moved into the Big Horn Basin in 1893, and between 1893 and 1913 an extensive flume system used water from the Tongue River to transport ties for railroad construction (Moulton 1995). All of the ties used by the transcontinental and regional railroads came from adjacent mountains, and were often transported to surrounding lowlands along stream courses or wooden flumes. By 1899, the Bighorn Region had 1,051 adjudicated rights to water flowing from the Big Horn Mountains, as well as 269 claims recorded and approved but not adjudicated, and approximately 100 ditches in use without claims (Mead 1899). More than a thousand holders of water rights used the diverted water for agricultural irrigation, cattle ranching, flour mills, and placer mining.

In general, the Big Horn Mountains and surrounding lowlands have had and continue to have low population densities relative to other regions of the country. There has been little mining in the area. However, cattle ranching, crop irrigation, and the associated flow regulation and diversion, as well as railroad construction and the associated timber harvest, have had substantial impacts on stream processes in many parts of the mountains. Other locally heavy human impacts include recreational activities during the 20th century.

Anthropogenic Influences on Aquatic, Riparian, and Wetland Resources

The human history of the Big Horn Mountains implies that many streams have been altered by changes in channel geometry caused by beaver trapping and tie drives; changes in flow regime, sediment transport, and riparian vegetation and bank resistance associated with flow diversion and regulation; increased water and sediment yield associated with timber harvest; decreased riparian vegetation and bank stability associated with livestock grazing; and, more recently, localized recreational impacts such as off-road vehicles.

Aquatic, riparian, and wetland ecosystems are influenced by past and current human disturbances. This aquatic, riparian, and wetland assessment describes over 20 significant anthropogenic (human) influences for the Bighorn landscape and analyzes their effects on hydrology, water quality, stream channel dynamics, aquatic habitats, riparian and wetland soils, and vegetation at each scale.

Additive Effects and Relationship of Ecological Driver and Anthropogenic Influence Analysis

A goal of this assessment is to integrate the results of the ecological driver and anthropogenic analyses for small watersheds, to interpret current conditions and identify effects influencing aquatic, riparian, and wetland habitats. Current conditions of aquatic, riparian, and wetland ecosystems, in each small watershed, result from additive effects of human influences in the watershed and upstream watersheds. Effects vary depending on the combinations of ecological drivers (climate, geology, glacial history, and stream gradient) present and their sensitivity to various anthropogenic impacts. Synthesizing results of ecological driver and anthropogenic influence analyses will provide a framework for managing the influence of these additive effects.

According to the National Environmental Management Act (NEPA) of 1969, the additive effects of management activities must be evaluated as part of any proposed action affecting federal lands. The synthesis of the ecological drivers, anthropogenic influences, and additive effects into management recommendations proceeds in three general steps: 1) grouping anthropogenic influences; 2) calculating and analyzing additive effects; and 3) comparing additive effects and ecological driver results.

Initially, we grouped specific anthropogenic activities into more general "use" categories (Winters et al. 2003a). For example, activities like roads, trails, railroads and off-highway vehicle use are grouped into the transportation category, on the assumption they exert similar influences on aquatic, riparian, and wetland resources.

Second, additive effects were calculated in two ways. One process added the rank of measurements derived from specific activity analyses within a particular use category. The HUBs with the highest values would correspond to those areas with the largest number of measurements with the highest ranks. In contrast, if an activity had none of the activities in a use category, the rank values would be zero. This analysis will provide a way for specialists to address the additive effects of a group of activities that have similar influences. The second process used an agglomerative cluster analysis for the measurements made within a use category as described by Cooper et al. (2003a), which produces clusters of 6^{th} level HUBs with similar influences. An explanation of the results of the cluster analysis is given that describes the "degree" of influence within a specific cluster.

Third, the results of the additive effects and ecological driver analyses were compared. Since both the ecological drivers and the anthropogenic influences are measured and analyzed at the same scale, this process becomes less difficult. These results are synthesized to determine the potential "sensitivity" of a particular cluster group to particular management activities. By comparing the level of influence (anthropogenic factors) with the potential sensitivity (ecological drivers), conclusions can be made concerning the overall condition of the 6^{th} level HUBs at the management scale.

Chapter 2
Ecological Driver Analysis

Introduction

Ecological driver analysis is based on protocols developed by Winters et al. (2003a), which define broad scale drivers to be used for a specific analysis. Ecological drivers are environmental factors that exert a major influence on the fitness of individual organisms and their populations, and help constitute the physio-chemical template of an ecosystem. A combination of three ecological drivers was used to assess the aquatic, riparian, and wetland ecosystems in the Bighorn Forest assessment area.

The drivers identified for the analysis of riparian and aquatic analysis were geology, climate, and stream gradient characteristics. These drivers influence the riparian communities, fish community distribution and abundance, instream production, and sediment transport dynamics.

The drivers identified for the wetland analysis included geology, climate based on precipitation type (rain vs. snow), and the presence or absence of glaciation, because they are the major factors influencing the distribution and abundance of wetlands.

An agglomerative cluster analysis was used to identify 6th level hydrologic unit boundaries (HUBs) or small watersheds that have similar percent area with each driver combination and the percent coverage was determined by a GIS analysis.

This cluster analysis was performed at two scales using the same driver combinations. First, the landscape analysis included the 248 6th level HUBs to address the characteristics of the area or landscape in which the Bighorn National Forest resides. Second, a management scale analysis included the 74 6th level HUBs that intersect the Bighorn National Forest to focus on the specific management needs of the USDA Forest Service.

Spatial and temporal heterogeneity is inherent in any type of assessment (Bailey 1995). Such heterogeneity tends to increase with scale, making large-scale comparisons more difficult. In this multiple scale assessment process, we have tried to balance the cluster analysis results with our ability to interpret between different clusters. For example, using too many clusters would not allow us to differentiate between various cluster characteristics, whereas using too few clusters would not be meaningful from a management standpoint.

The decision to use a particular level of similarity between clusters (e.g., cut point) was based on a consensus by team members on where the best differentiation occurred between clusters, without sacrificing the management context. Validation studies are under way to test these decisions.

Lentic or standing water environments (e.g., ponds and lakes) were not addressed as rigorously as other wetlands and lotic systems (e.g., streams and rivers). The influences of artificial or man-made reservoirs were addressed in this analysis, but their influence on fishery resources and aquatic productivity was not addressed. Region 2 will consider a more complete analysis of lentic systems in the future.

Key Findings

Stream/Riparian Ecosystems

1. There were 9 clusters of similar 6th level HUBs identified at the landscape scale. Clusters 3r, 4r, and 5r were the only ones that were located primarily within the BNF boundary (greater than 90% of their total area), while all other clusters occupied less than 20% within the Forest boundary.
2. Results at the landscape scale indicate that while USDA Forest Service management may have considerable influences on stream/riparian ecosystems types found in Clusters 3-5r. Our ability to significantly influence the overall stream/riparian characteristics found in Clusters 1r, 2r, and 6-9r are limited.
3. At the management scale, Clusters 1-3r comprise the 6th level HUBs with the highest concentration of riparian areas.

HUBs within these clusters contain abundant, high value riparian communities associated with a relatively high proportion of low gradient stream channels. While HUBs in Cluster 6r contain a higher percentage of low gradient streams, it is located in the plains region and barely intersects the BNF boundary.

4. There was an inverse relationship between the abundance of riparian shrub area and percentage of high gradient stream channels for each HUB within the BNF. Areas with low stream gradients could be important for plant and animal species that require relatively large riparian shrub communities as habitat.
5. The relatively high elevation and abundance of high and moderate stream gradients restricts the production of fish and other aquatic organisms at the management scale.
6. Clusters 2r and 5r would be considered to have the potential to have the highest production capability for fish and other aquatic organisms because of the relatively high percentage of low gradient stream channels, calcareous geology, and moderate to high elevations found in these clusters.
7. Because of the limited production capabilities within the BNF, low gradient stream reaches should be considered important production areas for fish and other aquatic organisms. These limited areas could be managed as such, as well as important recreational fishing areas because of their potential to produce larger adult fish.

Wetland Ecosystems

1. There were seven clusters of similar 6th level HUBs identified at the landscape scale. Clusters 4w and 5w were the only ones that were located primarily within the Bighorn National Forest (BNF) boundary (greater than 70% of their total area), while 48% of Cluster 3w was located within the Forest boundary.
2. Results at this scale indicate that while USDA Forest Service management may have considerable influences on wetland ecosystems types found in Clusters 3-5w our ability to significantly influence the overall wetland types found in Clusters 1w, 2w, 6w, and 7w are limited.
3. At the management scale, Clusters 1w, 2w, and 5w comprise the 6th level HUBs with the highest concentration of wetlands. HUBs within these clusters contain abundant, high value wetlands such as fens, lakes, ponds, and wet meadows. These clusters could be managed by a “watershed approach”, focusing on wetland related values.
4. There was a direct relationship between the percentage of lakes and ponds and the area of glaciated valleys (found primarily in Cluster 1w) within the BNF.
5. Clusters 3w, 4w, and 6w contain primarily isolated wetlands because of the steep terrain that probably could be mitigated through project implementation.
6. A comparison of the National Wetland Inventory (NWI) and BNF riparian and wetland inventory revealed that while the BNF inventory may have overestimated wetlands in certain areas, the NWI inventory underestimated wetland abundance by up to 10 times. Some refinement of the BNF inventory is suggested to strengthen this data.
7. Based on our knowledge of their location, the presence of rare wetland plants is likely to be highest within clusters of HUBs with abundant fens, wet meadows, and some cool north-facing foothills canyons (primarily Clusters 1w, 2w, and 5w).

Ecological Scales

The four spatial scales addressed in the assessment are: basin, landscape, management, and reach/site (fig. 2.1). A thorough discussion of the scales used for this assessment is provided by Winters et al. (2003a). Because of the very large area encompassed by the river *basin scale*, discussion is limited to the spatial and temporal scales as they relate to the Big Horn Mountains. For instance, a discussion of the first Euro-American inhabitants to the Big Horn Mountains is important because of their influence on beaver removal. Early settlement also had a significant effect on a variety of other anthropogenic influences, such as road and railroad construction, timber removal, tie drives, and cattle grazing. After the landscape scale is addressed the management scale's more specific analysis is discussed.

Using this multiple scale assessment approach, the most intensive analysis and description will occur at the levels that we have characterized as landscape and management levels. Reach/site analysis is impractical with this type of assessment because of the cost associated with intensive field inventory analysis. However, analysis at other scales could focus efforts at the site specific or reach/site scale to address specific questions identified through the multiple scale assessment.

We have made every attempt to address factors that influence landscape features related to aquatic, riparian, and wetland ecosystems, but watershed delineation cannot account for streams flowing across 6th level HUBs. At the landscape scale this is not an issue because stream systems are discrete for 4th level HUBs. However, the influence of upstream characteristics must be considered when analyzing influences at the reach/site scale.

Basin Scale

The Bighorn National Forest is nested within the 303,000 square mile Upper Missouri River Basin. The Forest lies in an isolated mountain mass surrounded by plains and composes only 1.1 percent of the basin's area. Mountain lands higher than 5,280 ft (1,600 m), such as the Big Horn Mountains, constitute less than 15 percent of the total basin area (fig. 2.2). These results indicate that the ecosystems and species associated with the Big Horn Mountains are quite rare in the context of the Missouri River Basin. Management considerations for these resources should take these results into consideration.

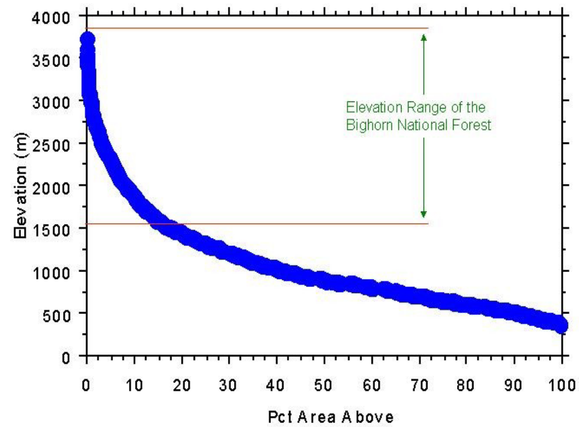


Figure 2.2. Hypsometric curve of the Upper Missouri River Basin.

River basins are ecologically distinguished mainly by differences in aquatic, riparian, and wetland species assemblages. For example, the rivers in the mountains of the Upper Missouri River Basin contain Yellowstone cutthroat trout, while the Middle Missouri and Upper Colorado River basins have greenback and Colorado River cutthroat trout, respectively. Similar distinctions apply to mollusks, invertebrates, warmwater plains fishes, and some riparian and wetland plants. The river basin assessment in this report addresses:

(1) Landforms and their development;
(2) The influence of the latest glacial period;
(3) Migratory pathways of aquatic, riparian, and wetland species between and within river basins;
(4) Ecological context of the Bighorn National Forest in the river basin; and
(5) General spatial and temporal human influences in the river basin.

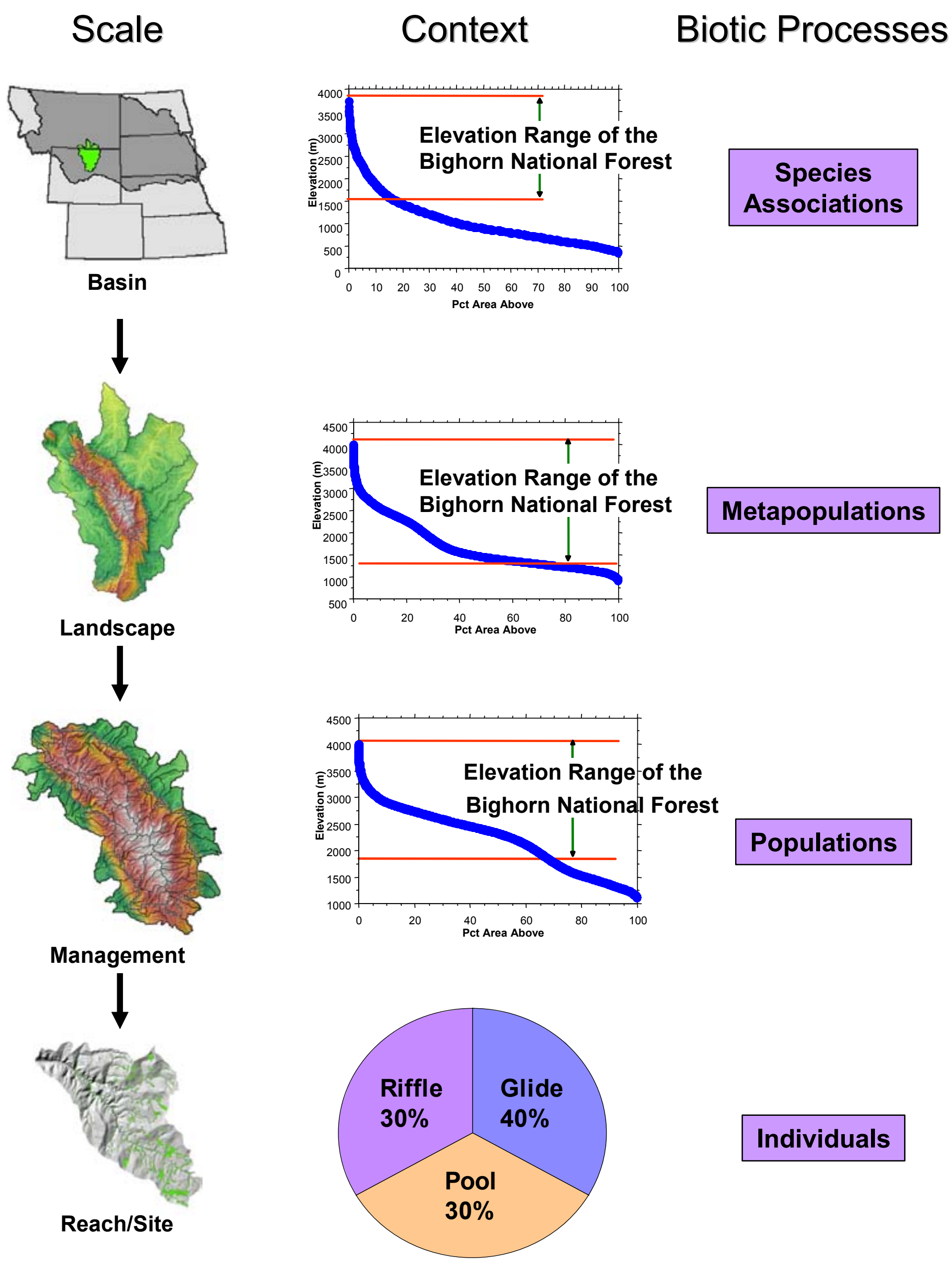


Figure 2.1. Scales, context and biotic processes for addressing aquatic, riparian, and wetland resources.

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Landscape Scale

The landscape scale is comprised of seven 4th level HUBs or sub-basins in which the Bighorn National Forest lies (fig. 2.3). These sub-basins drain the Big Horn Mountains into the Big Horn, Tongue, and Powder River systems. The Forest constitutes about 16 percent of the landscape's area of more than 10,700 square miles. About 35 percent of the landscape is higher than 5,280 ft (1,600 m) (fig. 2.4).

Ecosystems and species adapted to the higher elevations (e.g. Yellowstone cutthroat trout) are restricted in large part to the Bighorn National Forest at the landscape scale.

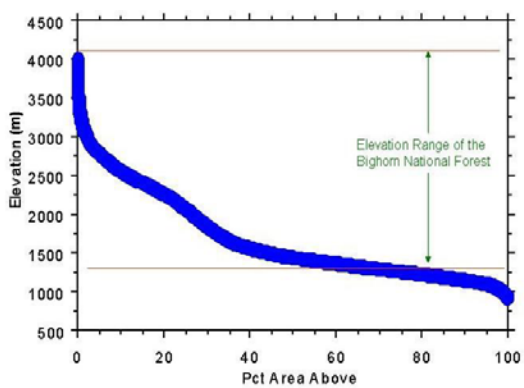


Figure 2.4. Hypsometric curve at the landscape scale of the Bighorn National Forest.

Management Scale

The management scale is comprised of seventy-four 6th level HUBs or small watersheds within or intersecting the Bighorn National Forest (fig. 2.5). These 74 small watersheds are nested within the seven landscape-scale sub-basins and cover about two million acres. Only 17 of these small watersheds lie completely within the National Forest boundary.

At the management scale, the aquatic, riparian, and wetland assessment refines the analysis conducted at the landscape scale. Other ecological drivers, such as extent of glacial activity and stream gradient, are added to the climate and geology drivers to extend the analysis, and additional data are integrated to better understand the following:

(1) Population distributions and dynamics of native fishes and other species;
(2) Distribution of high-value aquatic, riparian, and wetland ecosystems such as major wetland complexes;
(3) Sensitivity of small watersheds and their aquatic, riparian, and wetland ecosystems to disturbances;
(4) Extent of natural and human disturbances and their effects on aquatic, riparian, and wetland ecosystems;
(5) Historic and current conditions of aquatic, riparian, and wetland ecosystems; and
(6) Physical and biological restoration priorities for degraded aquatic, riparian, and wetland ecosystems.

Reach/Site Scale

This aquatic, riparian, and wetland assessment does not include analyses at the reach/site scale. However, specific features of riparian and wetland form, stream types, and aquatic habitat units are identified. The assessment addresses the spatial distribution of these features and how they may be affected by land use activities. Validation studies conducted at the reach/site scale will test the assumptions and measurements developed at larger scales.

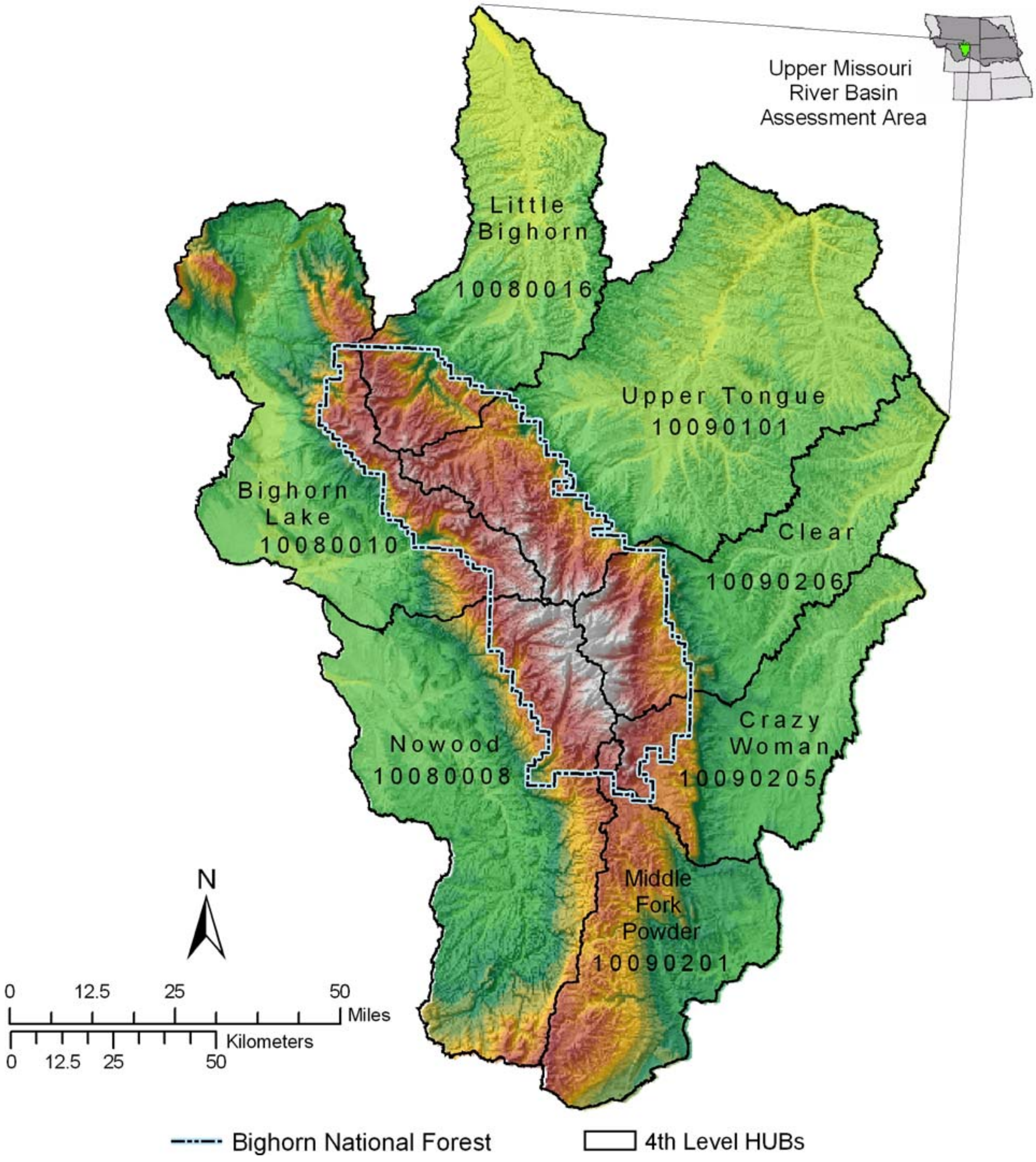


Figure 2.3. Landscape scale of the Bighorn assessment area showing 4th level hydrologic unit boundaries (HUBs) or sub-basins.

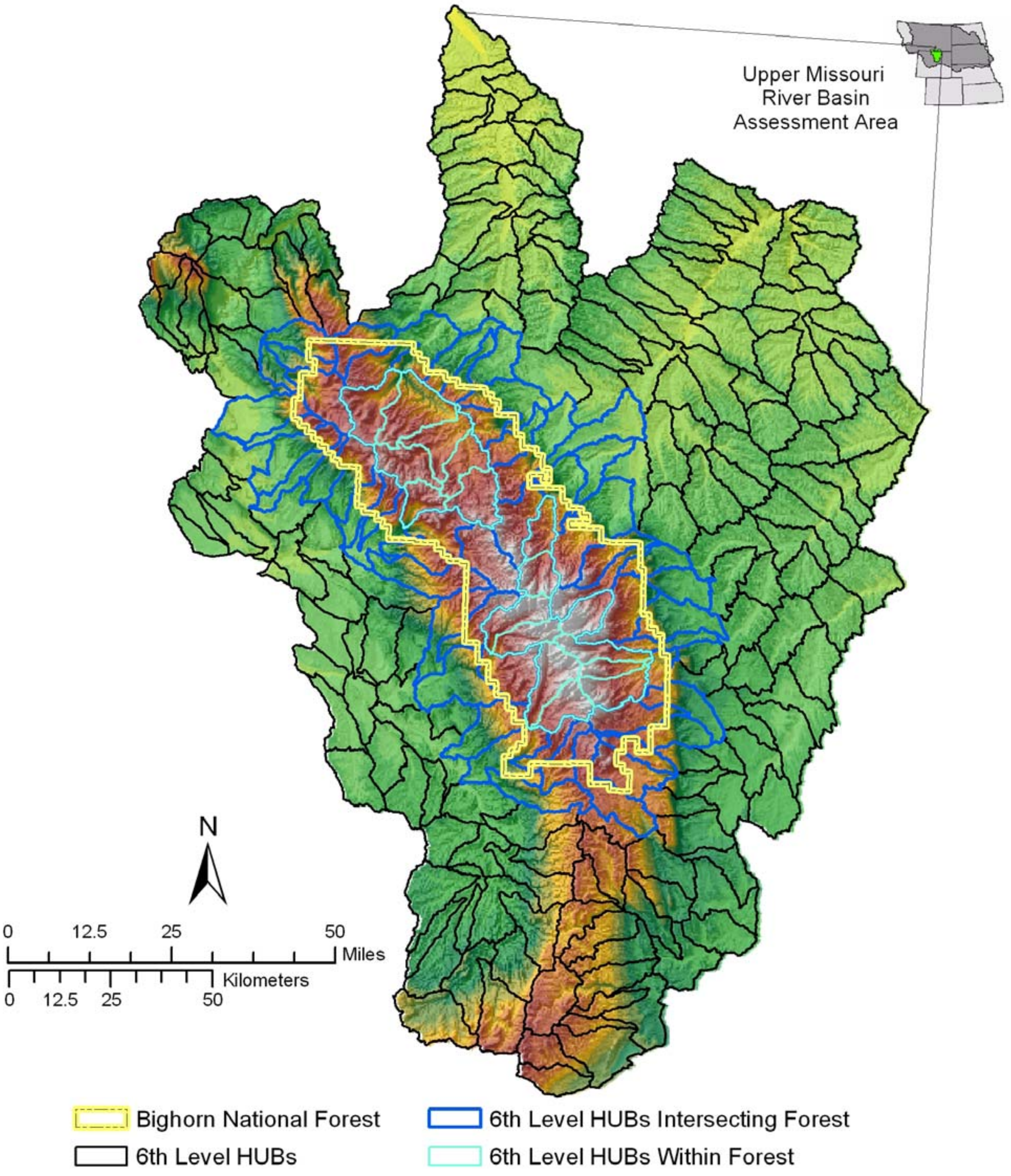


Figure 2.5. Management scale of the Bighorn assessment area showing 6th level hydrologic unit boundaries (HUBs) or watersheds There are 248 6th level HUBs contained within the seven 4th level HUBs associated with the assessment area. Only 74 6th level HUBs actually intersect the Forest boundary and 17 HUBs are entirely contained within the Forest.

Factors that Influence Species Assemblages at all Scales

The factors that influence species assemblages can be represented as a hierarchy of natural processes and anthropogenic alterations (fig. 2.6). Natural processes such as glaciation, mountain uplifts, filter the species pool and zoogeographic barriers to produce the landscape level (4th level HUB) species pool at the largest assessment scale or the basin level.

Anthropogenic factors that affect the landscape species pool include exotic species (Rahel 2000) or creation of transbasin water diversions that provide routes for species invasions (Mills et al. 1994). From this landscape level pool, the distribution of individual species at the management scale or 6th level HUB is often determined by large-scale habitat gradients related to climate (e.g., temperature and precipitation regimes), landforms, and surficial geology that determine the general types of aquatic habitats present in the region. Anthropogenic alterations important at this scale include reservoir construction, the creation of migration barriers, and fish stocking. At the reach/site scale, local habitat factors interact with biotic processes such as competition, predation, or disease to determine species abundances (Tonn et al. 1990). For example, important anthropogenic alterations operating at the reach/site scale include habitat degradation from livestock overgrazing, water quality impairment from sewage outfalls, and habitat improvement due to the addition of fish cover structures.

<u>Basin Scale</u> represents the broadest unit of analysis and the results of major geologic and biogeographical processes. This scale is characterized by aquatic ecoregions, which typically comprise part or all of a major river basin including large tributary systems and the associated riparian areas and wetlands in those basins. Examples of river basins in Region 2 include:

(1) Upper Missouri (Big Horn, Tongue, and Powder Rivers);
(2) Middle Missouri (North and South Platte Rivers);
(3) Southern Great Plains (Arkansas River);
(4) Upper Rio Grande (Rio Grande River); and
(5) Colorado River (Colorado River, San Juan, Gunnison, White, and Yampa Rivers).

The basin scale represents the historic, evolutionary limits of organisms that are restricted to aquatic environments within these systems. For example, the Forests in Region 2 include the headwaters of several river basins. In addition, four sub-species of inland cutthroat trout (*Oncorhynchus clarkii*) inhabit specific basins, e.g., the Yellowstone cutthroat in the Upper Missouri drainage, the Greenback cutthroat in the Middle Missouri and Southern Plains drainages, the Rio Grande cutthroat in the Rio Grande drainage and the Colorado River cutthroat in the Upper Colorado drainage. Interestingly, these cutthroat subspecies originated from the coastal cutthroat form and represent the evolutionary divergence that occurred as a result of isolation during past glacial periods.

Many warmwater fishes are restricted to river basins in the region. Indeed, similar species such as the northern redbelly dace (*Phoxinus eos*) found in the Middle Missouri drainage and the southern redbelly dace (*Phoxinus erythrogaster*), found in the Southern Plains drainage, are separated by basin divides that are less than one mile apart in some areas. Entire fish assemblages appear to exhibit species replacement between river basins (Baxter and Stone 1995).

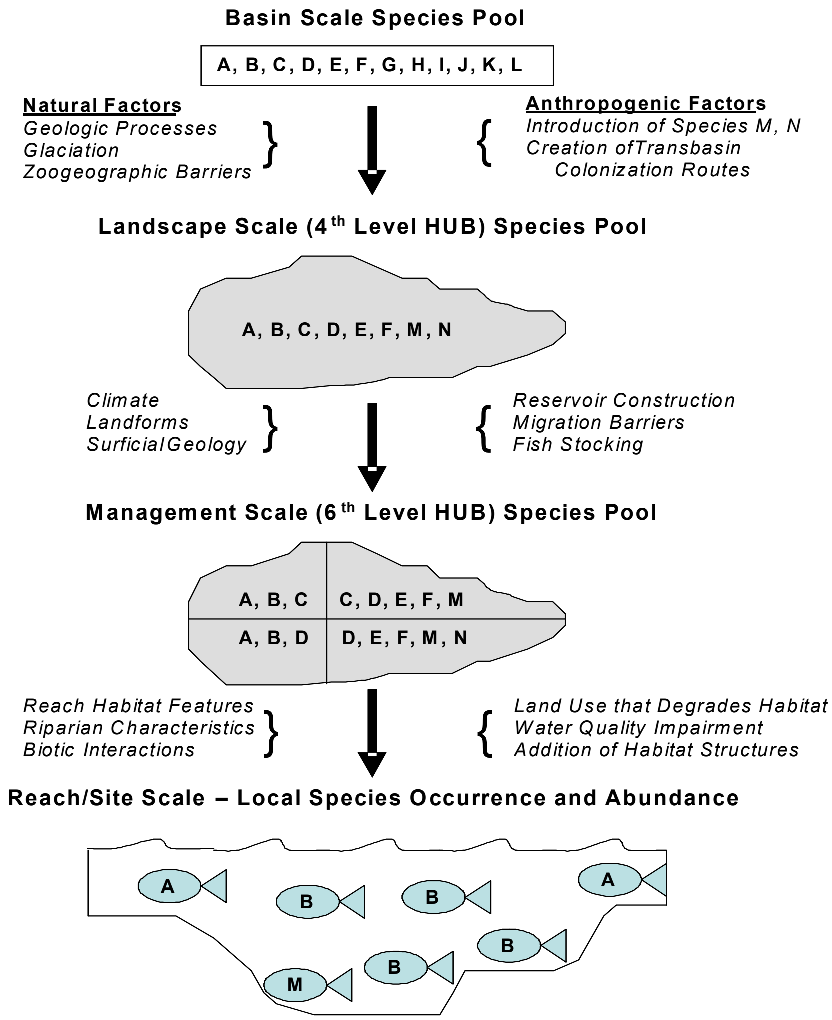


Figure 2.6. A hierarchy of natural and anthropogenic factors determines local species abundances. The basin scale species pool (species A through L) is reduced through natural processes that act as filters to prevent some species from occurring in the landscape scale species pool. At the management scale, the distribution of species is governed by climate, landform, and geology. At the reach/site scale, local habitat conditions and biotic interactions influence species abundances. Anthropogenic factors modify natural processes at each level of the hierarchy. Examples include enhancing the landscape species pool through introductions (species M and N), modifying species distributions by reservoir construction, and altering local abundances by habitat degradation.

Although less understood, other organisms such as mollusks and aquatic macroinvertebrates, are likely to also exhibit speciation within river drainages (Pennak 1978).

The importance of using the basin scale is to identify the areas for analysis at smaller scales, which may influence management of a particular native species. For example, a Forest may want to consider habitat conditions and restoration treatments based on the historic range of a species or ecosystem type rather than being based on administrative boundaries.

Analysis conducted at the basin scale is limited to narrative descriptions addressing the following:

(1) Landforms and how they developed.
(2) Influence of the last glaciation period.
(3) Evolutionary pathways of fish and other organisms through the influences of glaciation and longitudinal movements in stream systems.
(4) Position of National Forests and Grasslands in the landscape.
(5) Relative amount of National Forest System land in the context of the basin.
(6) Anthropogenic influences both spatially and temporally.

Hypothetical Management Example: There are two National Forests within a given river basin. As in almost all the basins associated with Region 2, there is an endemic cutthroat in this basin. Analysis at the landscape or management scales that are within this basin reveal that there is only one 6th level Hydrologic Unit Boundary (HUB) associated with both Forests which have the characteristics optimum for native cutthroat trout production. Rather than focusing on areas within both Forests, it would be more effective to focus on the one best HUB. Without this basin level context, lesser productive HUBs could be inadvertently identified.

<u>Landscape Scale</u> encompasses the management unit addressed in Forest planning. At the landscape scale we include all 4th level HUBs that intersect the particular Forest or Grassland we are addressing (fig. 2.3). The outside boundary of these units is identified as the limit of the landscape scale. Individual 4th level HUBs will be compared to others and will consider the magnitude of anthropogenic impacts that exist within their boundaries.

Some analyses will be limited to Forest Service jurisdictional lands whereas other analyses will occur within the entire watershed depending on management needs and available information. Factors will be identified that have utility at this analysis level, and these factors will determine what measurements are to be used and the level of specificity required to determine areas of similar ecological form and function.

Hypothetical Management Example: Analysis at the landscape scale reveals that the ecological characteristics identified at this scale are considerably different within the National Forest boundary than outside. The area within the National Forest boundary is also considerably less than outside. These results would indicate that the ecological conditions within the National Forest boundary related to aquatic, riparian, and wetland resources may be relatively rare in the context of the bigger landscape and should be considered appropriately in management contexts.

<u>Management Scale</u> incorporates the analysis conducted in the landscape scale and further refines the process within the management scale boundary (fig. 2.5). This spatial level of analysis corresponds to a 6th level HUB that intersects the appropriate administrative boundary. Analysis at this scale is very important for the Forest Service because we can utilize the information from the landscape analysis scale to understand form and function similarities at a finer scale.

The 6th level HUB is used because it is generally perceived as a manageable spatial unit in the Forest Service, important for measuring effective population size for native fish (Rieman et al. 2000), and is based on watershed delineations used by other state and federal agencies. Information will be incorporated from the landscape scale as well as additional drivers. This will enable statistical analysis of each watershed in comparison with others to determine which watersheds "should" function similarly. By knowing this, at the next finer scale we can compare across watersheds to understand each watershed's relative condition.

This is the appropriate scale to address management influences (e.g., anthropogenic disturbances) for a landscape assessment. These watersheds are fairly similar in size, making measurements such as road density, grazing density, and other anthropogenic influences more comparable. By addressing these issues at a 6th level HUB; watersheds that are most in need of restoration can be identified.

The 6th level HUB scale allows us to address high value systems. Although wetlands and riparian systems may be protected on a site basis, we may find that some watersheds have an inordinately large number of fens or other wetland types. These may be set-aside as protection areas. In addition, if we look at the appropriate factors in the assessment, we can identify watersheds that should be a high priority for recovery of native species, such as cutthroat trout. By going through this analysis we may find that some watersheds have the attributes that will increase the odds of recovery relative to others (e.g., watersheds without a high number of diversions). This is also an appropriate scale to assess risk from a management context, e.g., which watersheds are at a higher risk from particular anthropogenic disturbances based on the ecological driver analysis.

Hypothetical Management Example: Analysis of 55 6th level HUBs associated with a particular National Grasslands reveals that only six have characteristics, which are favorable for abundant wetlands. Existing wetland inventories reveal that indeed, approximately 45% of all wetlands at this scale are located in these HUBs. Information can now be incorporated in the Forest Plan to ensure that these areas are considered appropriately in management direction.

<u>Reach/Site Scale</u> analysis can identify important and measurable fine-scale attributes in watersheds, including specific riparian and wetland forms, channel types, and stream habitat units.

Although reach/site measurements will not be gathered as part of this multiple scale assessment, it is important that features influencing aquatic, riparian, and wetland habitats at this scale be identified. Whether these habitat types should be expected on the landscape and how they may be significantly impacted by land use should be assessed. The protocol provides guidance to Forest personnel regarding the important parameters that need to be identified and measured at the reach/site scale to make planning consistent with the context established by the multiple scale assessment.

Hypothetical Management Example: Analysis at the management scale reveals that there were three 6th level HUBs, which contain characteristics conducive to abundant riparian vegetation communities. Two of these HUBs have had historic management practices occurring in them that have limited riparian vegetation development. The other HUB is located in an isolated part of the National Forest and has received very limited management. Reach and site level measurements of key characteristics within this HUB can be used as reference levels for restoration goals in the two other impacted HUBs.

Bighorn Ecological Driver Definitions

<u>Geology</u>

The Big Horn Mountains have a core of Precambrian-age (2.5 billion year old) igneous and metamorphic rocks. The northern mountains have a granitic core, whereas the southern mountains have a core of gneiss. The flanks of the mountains are composed of younger, Paleozoic- and Mesozoic-age (500 to 60 million year old) sedimentary rocks, which dip steeply away from the center of the mountain mass toward the adjacent basins. The uplift, which produced the present mountainous topography, occurred during the Laramide orogeny, a massive episode of tectonic deformation, which created mountain ranges throughout the West. The Big Horn Mountains were uplifted circa 65 million years ago during thrust faulting, which displaced the core of the mountains from the southwest toward the northeast (Crowley et al. 2002). The mountains presently have the form of a doubly plunging anticline or fold, with steeper topography on the eastern side.

Geology sets the template for variation in size and composition of sediment throughout the Big Horn Range. At the northern end of the range, the granitic rocks are likely to weather to fairly coarse-grained sediment, such as sand, gravel, and cobbles. At the southern end of the range, the gneissic rocks are more likely to produce finer, sand- to silt-sized sediment. At lower elevations within the mountains, the valleys are more likely to be narrow and steep as a result of predominantly river, rather than glacial, erosion. The specific type of sedimentary rocks present along the valley will control the weathering regime and sediment production.

The chemical composition of the surficial geology significantly influences aquatic, riparian, and wetland ecology. The riparian, aquatic, and wetland environments are sensitive to the sediment being produced upstream and upslope. The species and habitats in these areas are influenced by, and adapted to, the sediment regime of the drainage basin. For the purpose of the Bighorn aquatic, riparian, and wetland assessment, it is important to differentiate between *calcareous* and *non-calcareous* lithologies (fig. 2.7). For the purposes of this analysis, calcareous geology is labeled “Ca” and non-calcareous geology is labeled “Cn” in tables and figures (table 2.1).

Calcareous rocks contain calcium carbonate ($CaCO_3$). This includes sedimentary rocks such as dolomite and limestone, as well as metamorphic rocks (e.g., marble) derived from calcareous sedimentary rocks. *Non-calcareous* rocks do not contain calcium carbonate, and include igneous rocks, sedimentary rocks, such as shales, sandstones, mudstones, and siltstones, as well as metamorphic rocks derived from non-calcareous parent rocks, such as gneiss, schists, and quartzites.

Weathering processes affect calcareous and non-calcareous rocks differently. Calcareous rocks weather by solution. The weak acids in rainfall, groundwater, and snowmelt react with the calcium carbonate in the rock. As this occurs, minerals are carried away in solution. The solution resulting from this weathering process is introduced into surface and ground water. As a result of the chemical reactions between the calcium carbonate and the acids in the water, the chemistry of the solution differs from that of the rainfall, snowmelt, or groundwater. Runoff or groundwater percolation introduces this solution into stream, riparian, and wetland habitats. This solution consequently interacts with the rainfall, snowmelt, or groundwater to influence aquatic, riparian, and wetland biota.

Non-calcareous rocks weather by mechanical processes, including frost action, crystal growth, and attrition of particles as they are transported by wind, water, ice, or gravity. The physical structure of the rock influences the size of the sediment produced by weathering. Crystalline rocks such as granites, diorites, basalts, and gabbros will produce particles ranging in size from boulders to silts or very fine sands. Sandstones will weather into sand sized particles. Siltstones and shales will produce silt and clay size particles, respectively.

Table 2.1. Driver definitions used for the Bighorn National Forest aquatic, riparian, and wetland assessment.

Assessment	Driver	Description	Abbreviation	Analysis Measurement
Riparian, Wetland, and Aquatic	Geology	Calcareous	**Ca**	Percent watershed area covered by calcareous rocks
		Non-Calcareous	**Cn**	Percent watershed area covered by non-calcareous rocks
Wetland	Glaciation	Glaciated	**Qa**	Percent watershed area glaciated during the Pleistocene and Holocene
		Unglaciated	**Qn**	Percent watershed area not glaciated during the Pleistocene and Holocene
Riparian, Wetland, and Aquatic	Climate	Snowmelt	**Ps**	Percent watershed area with hydrology controlled by precipitation as snow
		Rain-and-snow	**Prs**	Percent watershed area with hydrology controlled by precipitation as rain-and-snow
		Rain	**Pr**	Percent watershed area with hydrology controlled by precipitation as rain
Riparian and Aquatic	Gradient	Low	**Gl**	Percent stream length with low gradient reaches
		Moderate	**Gm**	Percent stream length with moderate gradient reaches
		High	**Gh**	Percent stream length with high gradient reaches

Influence of Geology on Wetlands

Geology or the bedrock type influences the rate of mineral sediment flux from hill slopes as well as the geochemistry of surface and groundwaters. Many igneous and metamorphic rocks decompose more slowly than sedimentary or volcanic rocks and produce less sediment. An abundance of sediment can fill basins in mountain landscapes reducing the area available for wetlands, and may limit the occurrence of specific types of wetlands. For example, high mineral sediment fluxes may fill kettle basins, and sediment deposited in wet meadows or on floodplains increases the relative water table depth, limiting the area of wetlands. Fens, with organic soils and exceedingly slow peat accumulation rates (~20 cm/1000 years in many areas; Chimner and Cooper 2003) cannot form or persist where the influx of mineral sediment from slopes exceeds the rate of organic matter accumulation.

Bedrock type also influences water chemical content, and natural waters in the Big Horn Mountains likely vary from being acidic with low mineral ion concentrations in areas with granite and metamorphic rocks, to basic with high concentrations of mineral ions in watersheds with limestone, dolomite, and/or shale. Differences in mineral ion concentrations dissolved in groundwater which supplies fens influences plant species composition forming the mineral rich to mineral poor gradient (Sjors 1950; Malmer 1986; Cooper and Andrus 1995; Cooper 1996; Chadde et al. 1998). In addition, mineral ions may accumulate in marshes and wet meadows, which influences soil geochemistry, plant species composition, and community production (Winters 1989).

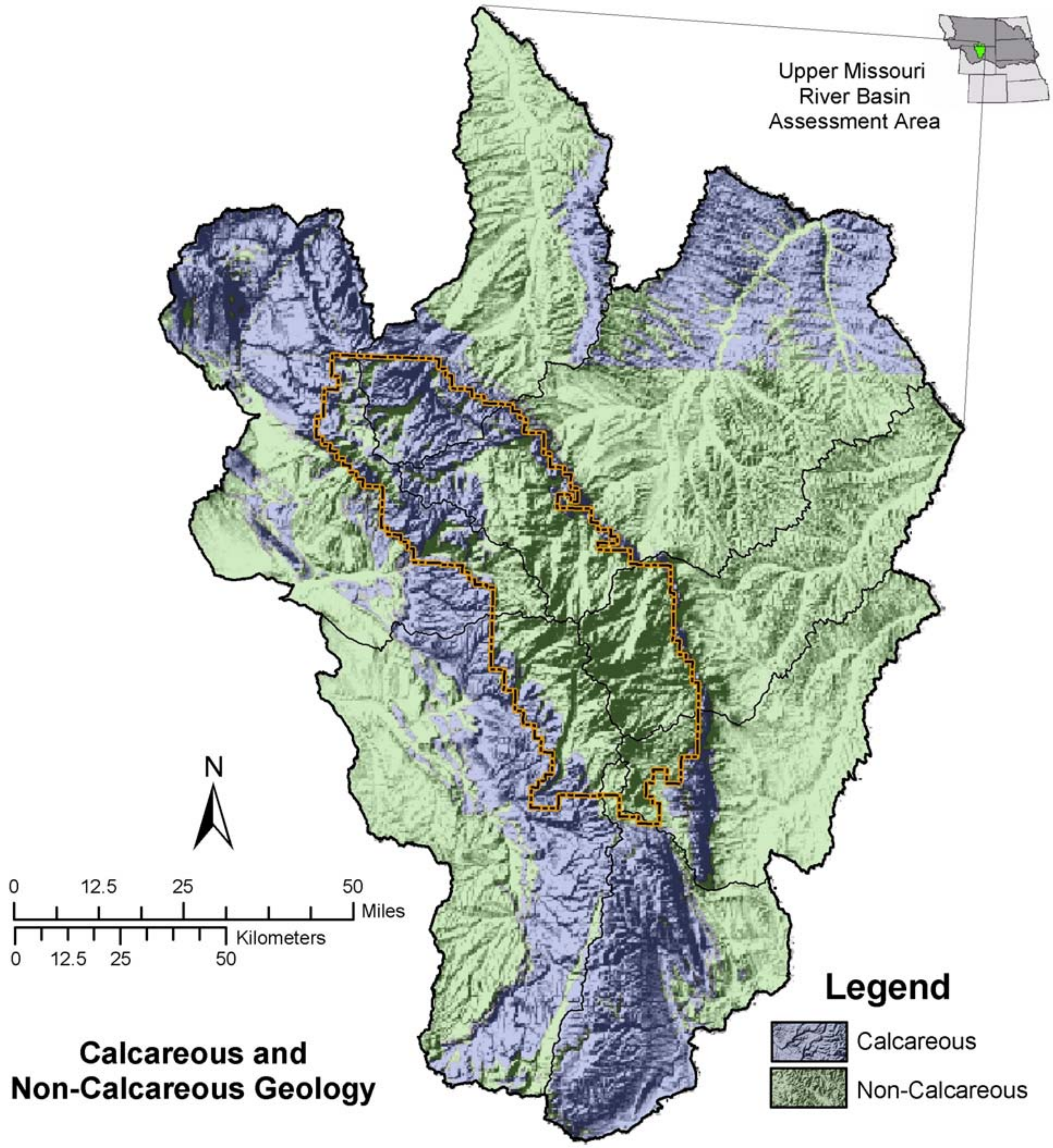


Figure 2.7. Distribution of calcareous and non-calcareous geology at the landscape scale. The sharp east-west edge to the calcareous rocks in the northeast reflects different mapping standards in the two source data sets from Montana and Wyoming.

Glacial History

The Big Horn Mountains were repeatedly glaciated during the Pleistocene (2 million to 10 thousand years ago), as were most of the mountain ranges in the Central Rocky Mountains. In the Big Horns, the latest phase of glaciation extended down to about 10,000 ft in elevation, and deglaciation was complete by 13,000 years ago (Porter et al. 1983). The Big Horn Mountains had primarily valley glaciers spreading from high mountain cirques. So in the glaciated valleys, the sediment is eroded from these headwater cirques and deposited lower in the valleys as moraines and other glacial features. Therefore thicker sediment only occurs at the lower elevations reached by the glaciers. Large, rounded glacial outwash boulders may be present in granitic bedrock areas affected by glaciation.

Rate of weathering combines with glacial history to determine valley geometry. The upper elevation, glaciated valleys are more likely to be u-shaped, with flatter downstream gradients, and with broad valley bottoms where weathered sediment can be stored. This sediment storage facilitates development of thicker soils and more subsurface water flow to streams. The broader valley bottoms also promote more sinuous streams, with more extensive riparian zones. Below the elevation of the Pleistocene glaciers, the valleys are more likely to be v-shaped, with narrow bottoms and steeper downstream gradients. This results in less sediment storage, greater movement of sediment and surface flow into the channels from adjacent hillslopes, straighter and more confined stream channels, and less extensive riparian zones.

Glaciated and unglaciated regions in the Big Horn Mountains are delineated in Figure 2.8. For the purposes of this analysis, glaciated regions are labeled as “Qa” and non-glaciated regions are labeled as “Qn” (table 2.1).

Influence of Glaciation on Wetlands

Glaciation during the Pleistocene created landforms in high elevation valleys that are conducive to the formation of wetlands. Glaciers erode headwater valleys and transport sediment down valley where it is deposited as lateral and terminal moraines, ground moraines, and other features (Ritter 1978). Terminal moraines have dammed many mountain valleys lowering the valley gradient upstream. This slows the flow of water and creates many of the largest wetland complexes in the Big Horn Mountains. Melting of ice at the glacial terminus as well as the formation of ice margin terraces has produced hundreds of kettle basins in the Big Horn Mountains, which support seasonal and permanent ponds and lakes, marshes and fens. These wetlands are critical habitat for amphibians, waterfowl, and many plant species. Glacial moraines are the largest bodies of unconsolidated material in many parts of the Big Horn Mountains, and store large volumes of groundwater, which is recharged annually by snowmelt. Where this water discharges in valley bottoms, it has led to the formation of fens and wetlands, augments stream flows, and moderates instream temperatures during summer.

Stream Gradient

Stream gradient influences stream power, stream erosive capability, and sediment texture in the channel and floodplain. High gradient streams typically have bedrock or coarse gravel and cobble channel beds. Floodplains also are typically narrow, or may be non-existent. Those that do exist typically have coarse-grained sediments. Floodplains with coarse-textured soils drain rapidly, and are periodically eroded by high-energy floods. These sites support primarily herbaceous vegetation, or woody plants that can tolerate periodic high-energy floods, and many support clonal plants, such as narrow leaf cottonwood (*Populus angustifolia*) and red osier dogwood (*Cornus stolonifera*) that sucker following flood disturbance. Low gradient streams typically have wider floodplains with finer-grained soils, and support diverse plant and animal communities. Low gradient stream reaches with extensive willow communities may also support beavers, ecosystem engineers that distribute water and sediment across the valley, increasing hydrologic and ecological complexity.

The stream gradient is subdivided into high, moderate, and low categories for this assessment. High gradient segments generally correspond to steep, narrow valley segments with a high connectivity between hill slope

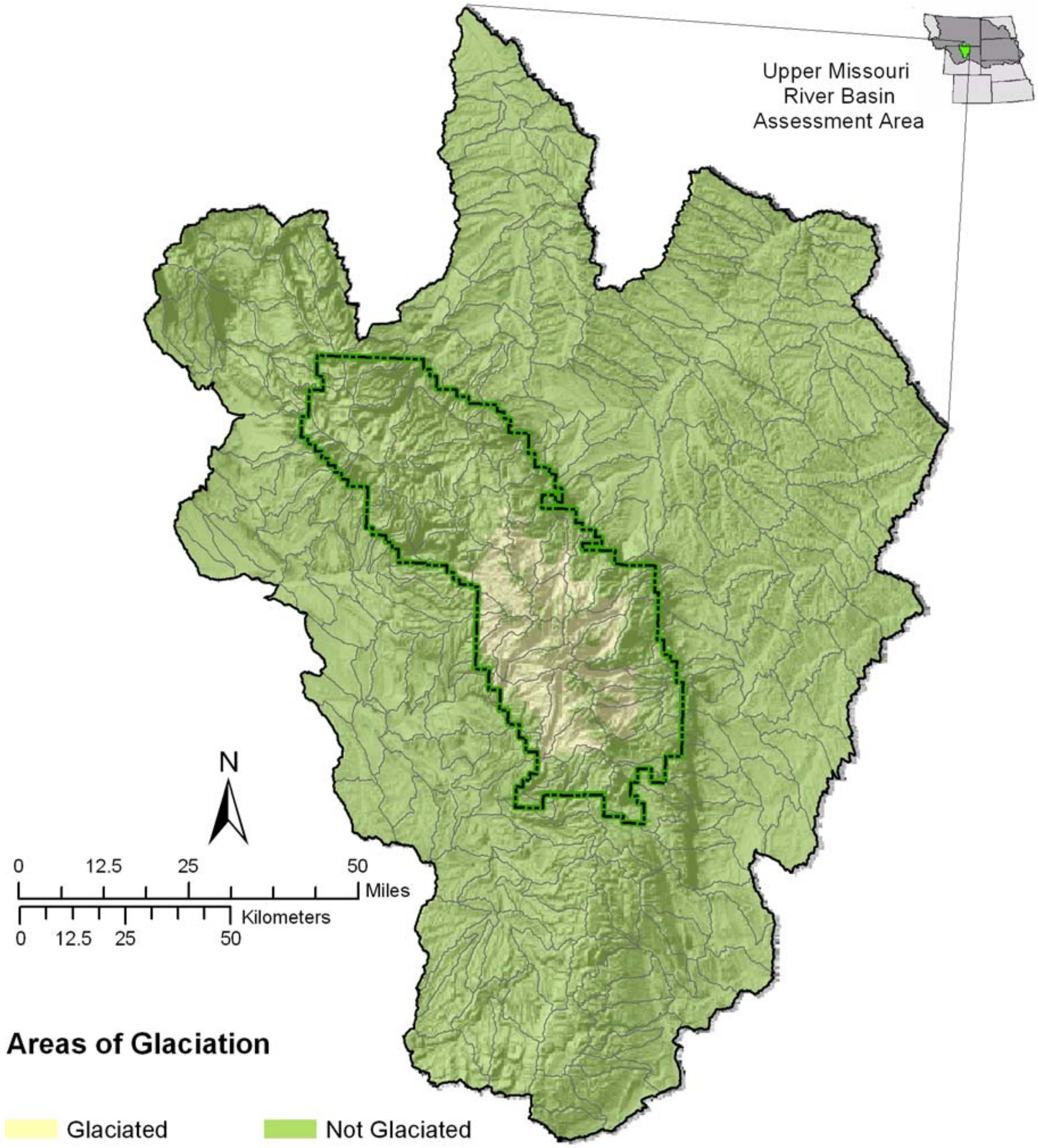


Figure 2.8. Glaciation map at the landscape scale of the Bighorn assessment area.

and valley bottom, and where debris flows and landslides can introduce coarse sediment directly to the channel. High stream gradient is correlated with presence of boulder-sized coarse sediment clasts, and a step-pool morphology that is fairly resistant to high-flow disturbances. Moderate gradient stream segments have wider valley bottoms in which some of the sediment transported from valley side slopes may be stored before reaching the active channel. Moderate gradient streams may be transitional between step-pool and plane-bed or pool-riffle morphologies, and are likely to have cobble- to boulder-sized coarse sediment. Low gradient streams have wider valley bottoms and greater lateral mobility compared to steeper, narrower valley bottoms. These streams are generally pool-riffle systems, with cobble-sized coarse sediment. For the purpose of this analysis, high gradient stream segments are labeled as "Gh", moderate gradient segments as "Gm", and the low gradient segments as "Gl" (table 2.1).

<u>Precipitation Regime (Climate)</u>

Precipitation in the Big Horn Mountains results primarily from winter snowfall or summer convective storms. The majority of the precipitation falls during April to July. The mountains have a strong orographic gradient, with mean annual precipitation of 34 inches at 9,380 ft dropping to less than 10 inches below 5,000 ft (Takacs et al. 1995). The eastern side of the range is slightly wetter, with mean annual precipitation levels of 10 to 15 inches to the north and northeast of the range (figs. 2.9 and 2.10).

The climate driver is divided into three categories based on annual hydrologic conditions: snowmelt, rain-and-snow, and rainfall. *Snowmelt* regimes are found at high elevation, and typically have cold temperatures. Snowmelt streams have less interannual variability than the other hydroclimatic types, and have a broader annual hydrograph with a lower peak and a longer duration than rainfall streams. R*ain-and-snow* or combined rainfall-snowmelt precipitation regimes occur at intermediate elevations. Streams influenced by rain-and-snow precipitation have an annual snowmelt peak during late spring and early summer, but rainfall-generated flash floods may also be superimposed on this peak during mid-late summer. *Rainfall* precipitation regimes dominate streams heading below the mountains, with an annual hydrograph dominated by rainfall-generated runoff. These streams have flashy hydrographs, with a larger peak and shorter duration than snowmelt streams. For the purposes of this analysis, the snow precipitation zone is labeled "Ps", the rain-and-snow precipitation zone as "Prs", and the rain precipitation zone is "Pr" (table 2.1).

Flow Regime

Precipitation interacts with elevation to influence the flow regime in the Bighorn assessment area. For example, higher elevations, although wetter, are likely to have streamflow regimes dominated by snowmelt, with a broad, lower-magnitude annual peak, and greater subsurface flow into channels. The lower elevation channels may have summer thunderstorm rainfall superimposed on the snowmelt peak flow. The thunderstorm rainfall will produce more surface runoff and more peaked, flashy floods.

Channel segments with flow dominated by snowmelt are likely to have more stable substrates than those with flow dominated by rainfall-derived runoff. Snowmelt-dominated channels are thus likely to have different disturbance regimes than rainfall-dominated channels.

Larger streams draining the Big Horn Mountains have a snowmelt dominated hydrologic (flow) regime. Examples of snowmelt-dominated rivers are the Nowood River (fig. 2.11) draining the SW portion, and the Tongue River (figs. 2.12 and 2.13) draining the northeast portion of the Big Horn Mountains. Both streams have low winter base flows, a sharp increase in flow during May, peak flow during June, and an equally rapid decrease in flow during July as the high mountain snowpack is depleted. In most years there are multiple flow peaks, resulting from the sequential melting low- and high-elevation snowpack. A few August and September peaks occur due to late summer rains (e.g., the Nowood River in 1984), but these are of short duration and have a lower peak than the snowmelt driven peak.

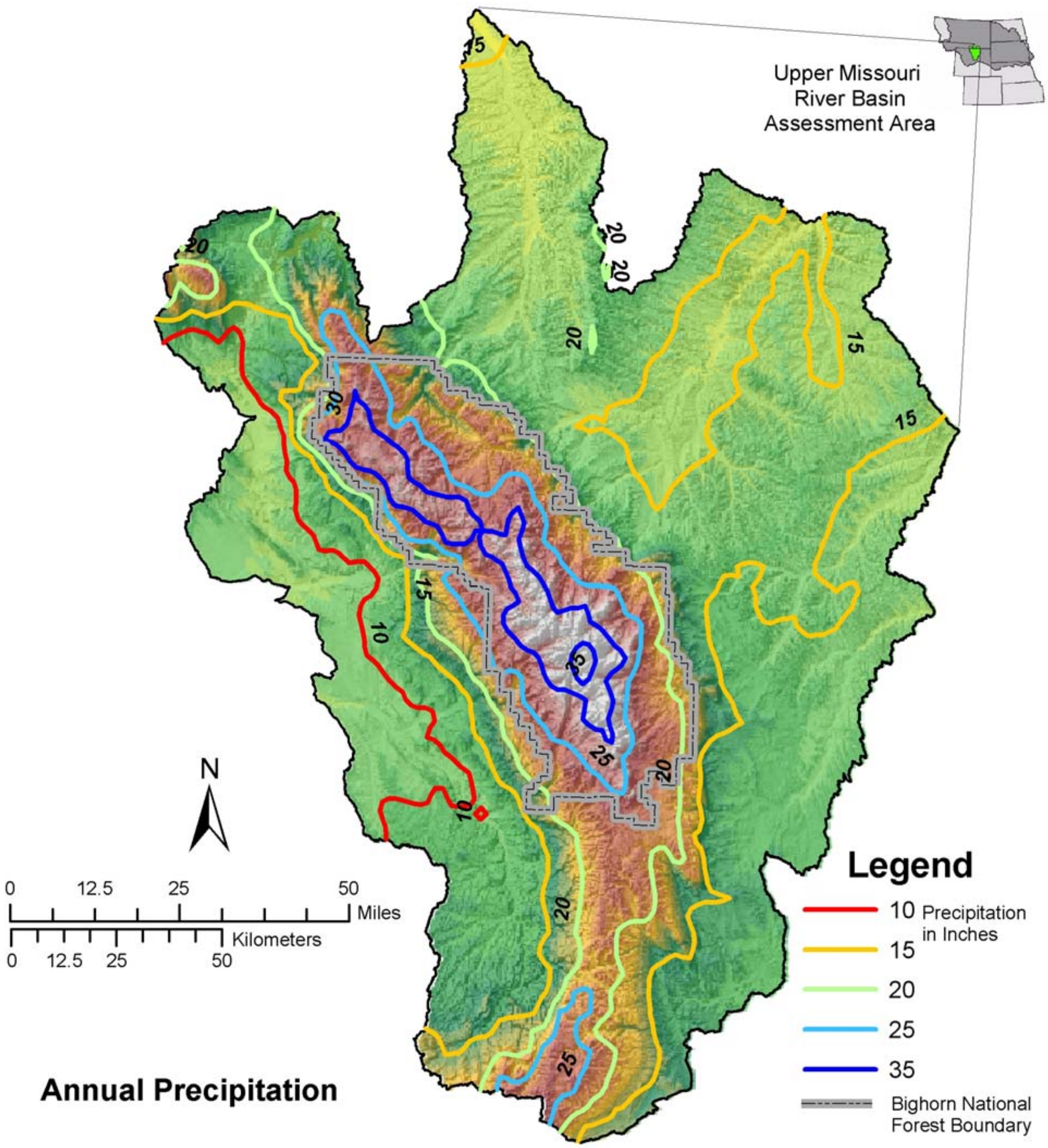


Figure 2.9. Isohyet map showing the equal contour lines of precipitation at the landscape scale.

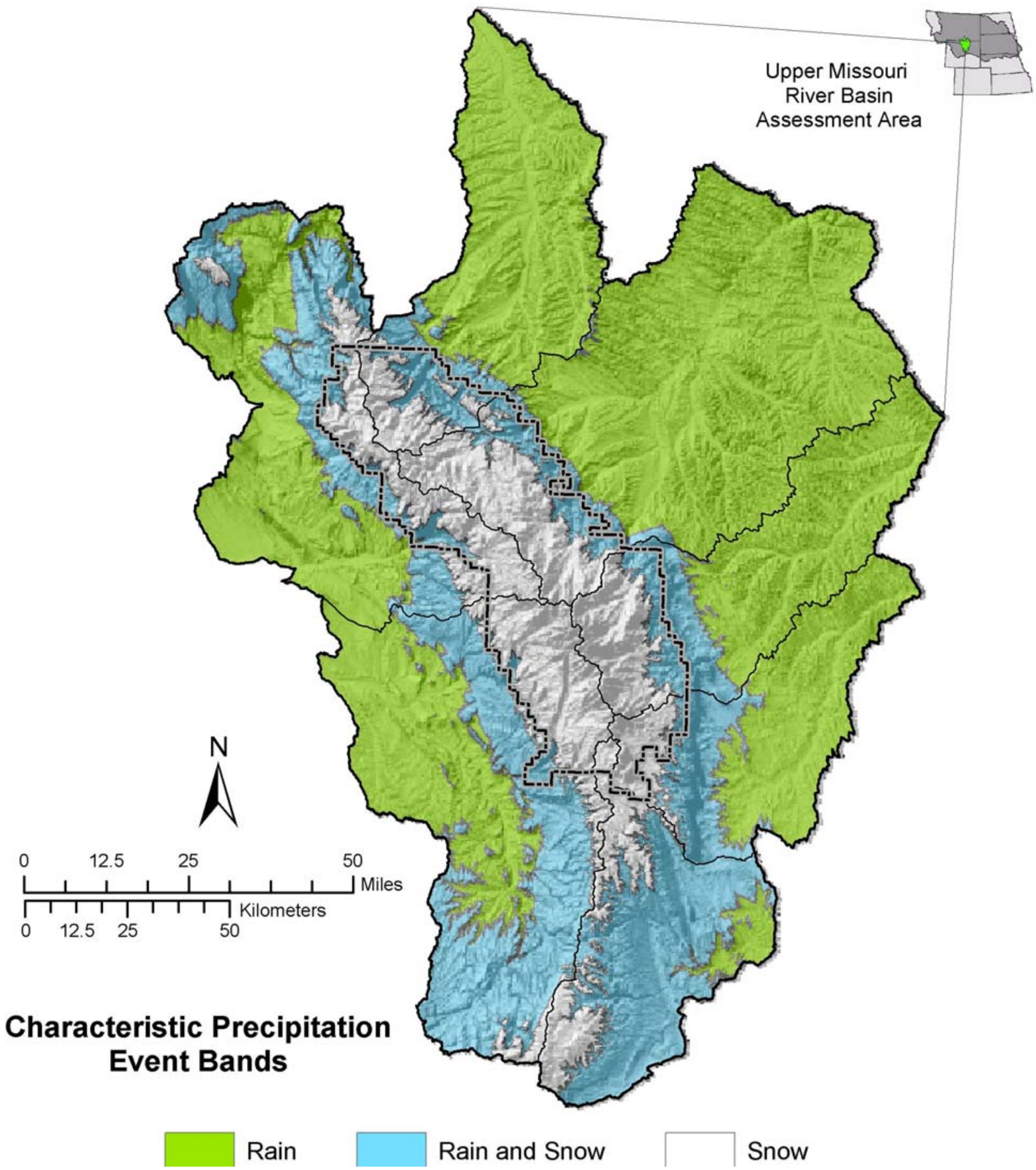


Figure 2.10. Map of precipitation bands at the landscape scale.

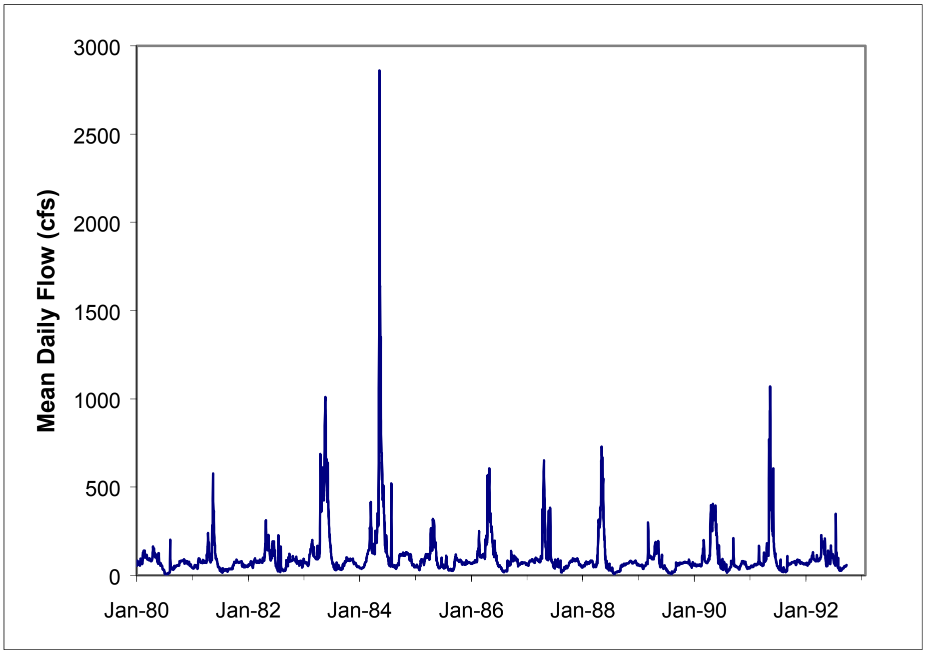


Figure 2.11. Mean daily flow of the Nowood River, 1980-1992. Note the inter-annual variance in peak flow (e.g., 1984 vs. 1985), the occurrence of multiple peaks per year (e.g., 1987), and the long period with very low flows during fall, winter, and spring.

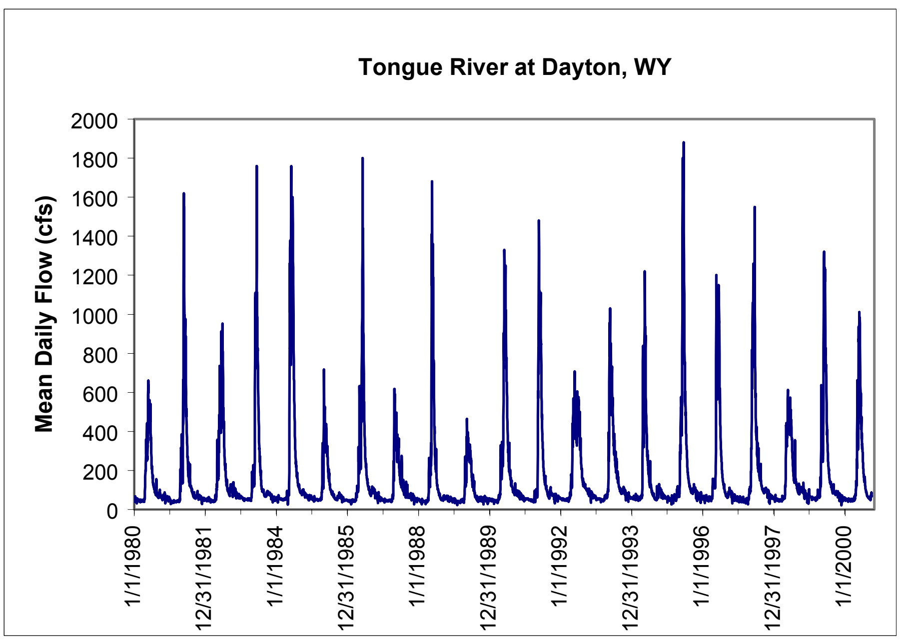


Figure 2.12. Mean daily flow of the Tongue River at Dayton, Wyoming, 1980-2000. Note the relative consistency of annual peak flows, compared with the Nowood River. The figure shows winter base flows are very low, while the period of snowmelt runoff has very high flows.

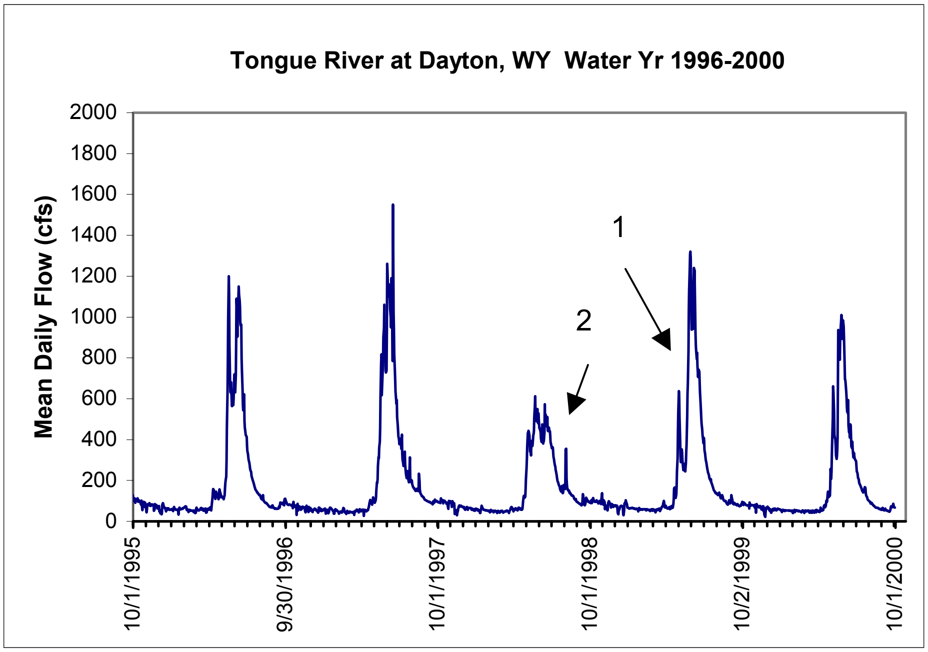


Figure 2.13. Mean daily flow for the Tongue River at Dayton, Wyoming, 1996-2000. Very low winter base flows end in May with the rapid melting of high elevation snow, which increases stream flow by 1-2 orders of magnitude. Several peaks occurred on some years, such as 1996 and 1999. In 1999, the first and smaller peak was driven by melting low elevation snow (see arrow 1). The much larger high elevation snowpack melted in late May producing the annual peak flow, which also had several peaks. Occasionally, as in 1998 (see arrow 2), a small late summer rain-driven peak flow may occur.

The magnitude of annual peak flow varies widely because of inter-annual variation in snowfall and melting rate. The annual peak flow of the Nowood River varies by an order of magnitude, while that of the Tongue River varies about half as much. The sharp rise in flow in early summer, and the high but variable peak drives fluvial geomorphic processes that create channel and floodplain landforms and bare soils suitable for the establishment of willow, cottonwood, alder, and other woody plant species. Low summer flow also influences the composition of riparian flora by favoring the establishment of deeply rooting species. Once established, these woody plants stabilize floodplain soils and cause sediment deposition within stands during flood events, which lead to floodplain accretion. The complexity of floodplain habitats is due to the varying age and vegetation of fluvial surfaces and riparian community succession. Woody riparian plants also shade streams, and provide allochthonous inputs of organic matter that can support aquatic food webs.

Except for larger streams and rivers, few data exist on hydrologic conditions in the Bighorn assessment area. For example, no gauging stations exist for streams with their headwaters in the foothills of the Big Horn Mountains, or groundwater monitoring wells in wetlands, such as fens or wet meadows. Therefore, it is hard to characterize the hydrologic regime of these wetland types relative to the larger gauged streams.

Influence of Climate on Riparian and Wetland Ecosystems

Climate controls the hydrologic regime of streams, influencing riparian ecosystems through the timing and magnitude of peak flows, and the perennial or intermittent nature of streams. Most precipitation in the higher elevation Big Horn Mountains is from snow, and these areas also receive much greater amounts of precipitation than lower elevation areas. The greater input of water via precipitation supports greater abundance of wetlands, and greater variation in wetland types, because large groundwater-driven wetland complexes are found only in association with snowmelt-recharged aquifers. Within the snow dominated precipitation zone, streams have a more predictable annual flow pattern, and experience fewer extreme floods. These streams are influenced by snowmelt recharge of hill slope aquifers, which provides groundwater to support perennial stream flow during the summer. Lower elevation watersheds dominated by rain or rain-and-snow driven hydrologic regimes tend to be flashier, with less predictability in timing and magnitude of the annual peak flow, and potentially higher peak floods relative to the mean annual flow. Many streams with headwaters in areas with rain and rain-and-snow precipitation regimes are intermittent and many lack riparian vegetation because perennial groundwater during the summer is too deep to be reached by the roots of riparian plants.

Ecological Driver Analysis for Riparian Areas Including Sediment Dynamics, Instream Production, and Fisheries

Landscape Scale

Riparian Cluster Analysis

Three drivers were chosen to analyze the influence of physical variables on riparian and aquatic ecosystems in the Big Horn Mountains: geology, climate (precipitation regime), and stream gradient. Landscape-scale agglomerative cluster analysis of riparian and aquatic ecosystems divided the 248 6^{th} level HUBs into nine clusters based on a 25% similarity cut point (fig. 2.14). There is an obvious separation between Clusters 1-5r and 6-9r, whereby Clusters 6-9r are all located on the Great Plains, and have rain-driven hydrographs and abundant low gradient stream channels (table 2.2). Cluster 8r is not located within the Bighorn National Forest, while Clusters 6r, 7r, and 9r are only found at the periphery of the Forest boundary (fig. 2.15).

Driver Composition of Individual Riparian Clusters

Cluster analysis showed that individual drivers were more evenly distributed for the riparian and aquatic habitats compared with the wetland habitats (cf. tables 2.2 and 2.12). For the riparian and aquatic ecosystem analysis, the majority of these calcareous dominated Clusters (1r, 8r, and 9r) are not located within the Bighorn National Forest, while Cluster 5r is located mostly within the Forest boundary (fig. 2.15). Hydrology of Clusters 1-5r is dominated by snow and rain-and-snow precipitation, while that of clusters 6-9r is dominated by rain. These distinctions reflect differences in elevation, whereby Clusters 1-5r are located primarily within the Big Horn Mountains and Clusters 6-9r are primarily located on the Great Plains. Moderate gradient streams dominate none of the clusters, while high gradient streams dominate all of the clusters associated with the mountain environments (Clusters 1-5r).

Lower gradient stream channels are commonly associated with wide stream valleys, meandering streams with relatively wide floodplains, and depositional stream reaches (Rosgen 1996; Wohl 2000). Increased riparian communities, and often times increased fish and aquatic production, can be found in these stream types in the mountainous ecosystems (Hynes 1970; Allan 1995). The paucity of low gradient stream channels suggests that these are unique areas that should be a focus of riparian and fishery management. For example, Cluster 2r is dominated by calcareous geology, rain-and-snow precipitation, and has the highest percentage of low gradient stream channels for those clusters located primarily within the Forest. These characteristics indicate a possibility for relatively high instream production and fishery related resources that should be protected.

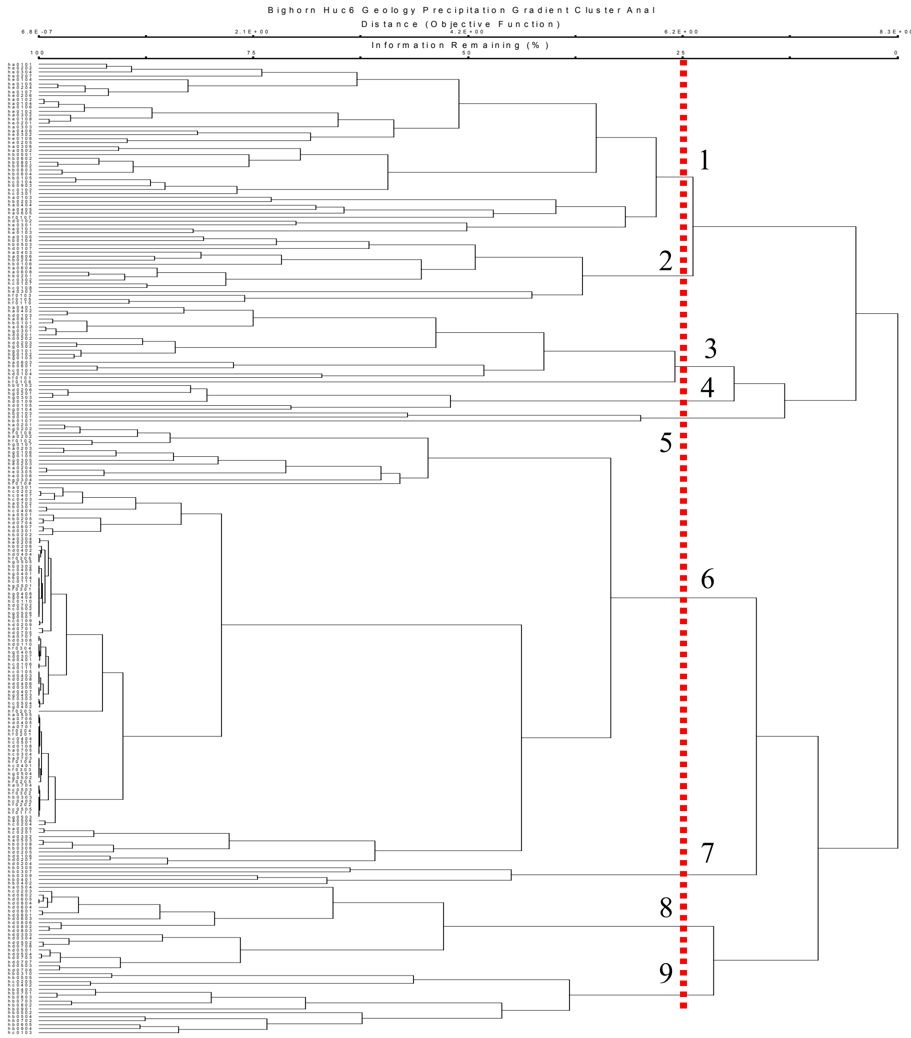


Figure 2.14. Landscape-scale agglomerative cluster analysis of riparian and aquatic ecosystems using the 248 6th level HUBs in the Big Horn Mountains assessment area. Geology, climate (precipitation), and stream gradient drivers produced nine distinct clusters. The dashed vertical line indicates the level of similarity or cut point used to define the clusters, and the numbers next to the line denote the clusters.

Table 2.2. Percent area encompassed by individual ecological drivers for the landscape-scale riparian and aquatic ecosystem assessment of 248 6th level HUBS in the Bighorn assessment area.

	Percent Area or Length Encompassed by a Specific Ecological Driver							
Riparian	**Geology**		**Climate (precipitation)**			**Stream Gradient**		
Clusters	**Ca**	**Cn**	**Pr**	**Prs**	**Ps**	**Gl**	**Gm**	**Gh**
1r	**84.37**	15.63	6.86	**76.35**	16.79	15.61	25.45	**58.94**
2r	**52.08**	47.92	42.73	**50.29**	6.98	34.02	21.51	**44.47**
3r	9.74	**90.26**	0.07	21.76	**78.18**	12.47	31.61	**55.92**
4r	12.15	**87.85**	2.76	**70.22**	27.02	5.74	18.26	**76.00**
5r	**58.70**	41.30	9.07	22.94	**67.99**	6.20	12.45	**81.35**
6r	5.43	**94.57**	**91.61**	8.25	0.14	**74.19**	19.41	6.40
7r	24.52	**75.48**	**64.98**	29.88	5.14	17.90	39.88	**44.63**
8r	**76.94**	23.06	**98.96**	1.04	0.00	**61.01**	30.84	8.15
9r	**84.95**	15.05	**76.23**	23.11	0.66	20.93	22.95	**56.12**

Ca *– calcareous geology,* ***Cn*** *- non-calcareous geology;* ***Pr*** *- rain driven hydrology,* ***Prs*** *– rain-and-snow driven hydrology,* ***Ps*** *- snowmelt driven hydrology,* ***Gl*** *- low gradient stream reaches* ***Gm*** *- moderate gradient stream reaches,* ***Gh*** *- high gradient stream reaches.*

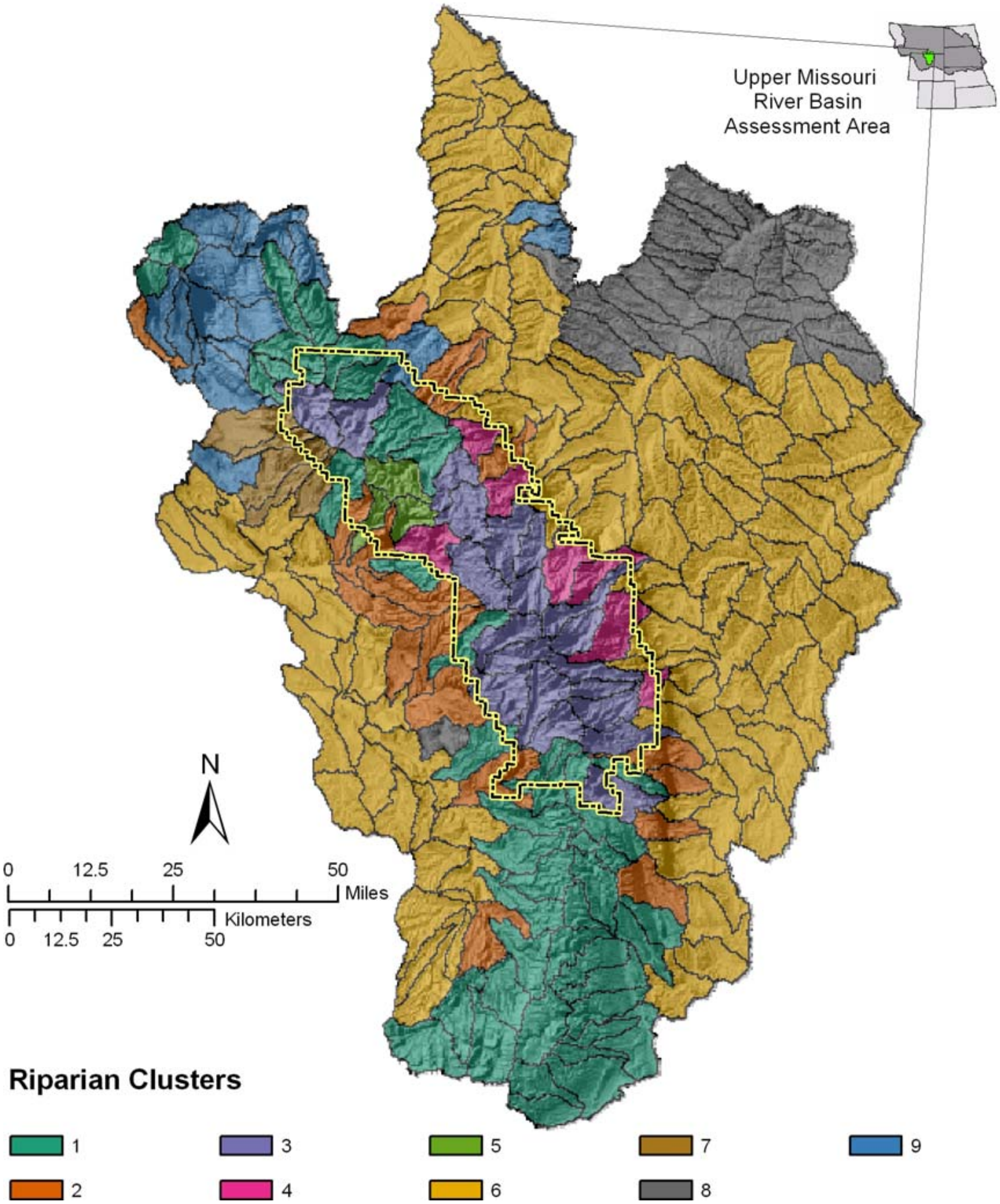


Figure 2.15. Distribution of nine cluster groups for riparian and aquatic ecosystems based on landscape-scale analysis of ecological drivers for 248 6th level HUBs in the Bighorn assessment area. Geology, climate, and stream gradient were the drivers used to produce the clusters.

Ecological Importance of Riparian Clusters at the Landscape Scale

Riparian Ecosystem Analysis

Agglomerative cluster analysis of riparian ecosystems using the 248 6th level HUBS (landscape scale) identified nine distinct clusters (figs. 2.14 and 2.15). Clusters 2-5r are within the Forest boundary and have a largely snow, and rain-and-snow driven precipitation regime, and are expected to have many perennial streams and significant groundwater flow. At higher elevations, tall willow, alder, and river birch communities dominate riparian zones, and cottonwood (*Populus angustifolia*) dominates at lower elevations. HUBs on the plains (e.g., Clusters 1r, 6-9r) will have plains cottonwoods (*Populus deltoides ssp. monilifera*) dominating the floodplains of perennial rivers and some intermittent streams. Sandbar willow (*Salix exigua*) is abundant along most plains streams. In general, riparian communities will be more abundant at higher elevations where more water is available, and lowest along plains streams that have been dewatered. However, the larger perennial plains streams that are hydrologically intact may have extensive riparian zones.

Invertebrate Diversity and Instream Production Analysis

The 248 6th level HUBS for the environmental drivers of geology, precipitation, and stream gradient fall into two distinct groups of importance to the aquatic productivity and diversity resource. Clusters 6–9r generally fall outside the Forest boundary on the Great Plains (fig 2.15). The rainfall dominated precipitation regime suggests these HUBs are likely characterized by seasonally intermittent streams. Given this harsh environmental setting, these HUBs will therefore generally have low aquatic productivity and diversity (del Rosario and Resh 2000) compared to perennial upland streams. Exceptions would occur where larger, perennial streams originating in the mountains flow out onto the plains. In those instances, high summer water temperatures would promote high primary productivity (especially in conjunction with anthropogenic nutrient additions) and an invertebrate fauna adapted to warm water and relatively low dissolved oxygen (Shieh et al. 2002).

By contrast, Clusters 1-5r are generally within the Forest boundary and are characterized by more snow-driven precipitation and higher stream gradients. These cool-water streams are likely to be perennial and thus support higher invertebrate diversity and continuous aquatic productivity. An exception may be Cluster 2r, which consists of lower elevation HUBs along the flank of the Forest boundary. This cluster shows a mixture of rainfall and rain-and-snow hydrology, as well as a mixture of stream gradients.

Fisheries Analysis

The first major division in the cluster analysis of the 248 6th level HUBs was Clusters 1-5r versus Clusters 6-9r. Clusters 1-5r are primarily higher elevation watersheds located within the Bighorn Forest boundary. Clusters 6-9r are composed of lower elevation 6th level HUBs that are largely outside the boundaries of the Bighorn National Forest (fig. 2.15). However, these watersheds are part of the seven 4th level HUBs that originate on the Forest (fig. 2.3) and activities that occur on Forest Service lands can impact aquatic organisms in these lower elevation watersheds. Because of their low elevation, watersheds in Clusters 6-9r receive most of their precipitation as rain (table 2.2) and would not be prime habitat for coldwater fishes. However, they would harbor an assemblage of largely native fishes dominated by minnows and suckers.

Cluster 1r watersheds are characterized mostly by calcareous geology and moderate thermal regimes as indicated by the high percent of the watershed area in the precipitation as rain-and-snow category (table 2.2). Thus, these watersheds should be located in the foothills where water temperatures are cold enough to allow survival of coldwater fish species such as trout but not so cold as to inhibit growth and reproduction (Mullner 2001). The calcareous geology would promote high nutrient concentrations and thus high fish production. Of all nine clusters, Cluster 1r has the highest percentage of watershed area characterized by the combination of calcareous geology, precipitation as rain-and-snow, and low stream gradients. This is the combination of drivers that is most favorable for coldwater fish production. Although this combination of drivers is the highest in Cluster 1r watersheds, it is rare even there, comprising only 9% of the watershed area. This suggests that Cluster 1r watersheds deserve special attention from the perspective of preserving the areas of the Bighorn Forest having the best conditions for coldwater fish production.

Cluster 2r watersheds have a mixture of geology and gradient categories but include the greatest proportion of lower elevation sites among Clusters 1-5r (table 2.2). The highest combination of drivers (31% of the area) is for the calcareous geology, precipitation as rain-and-snow, high gradient category (CaPrsGh). Although the geology and precipitation categories are favorable for fish production, high stream gradients would limit fish production. The second highest combination of drivers (24% of the area) is for the non-calcareous geology, precipitation as rain, high gradient category (CnPrGh). This is the least favorable combination of drivers for coldwater fish production.

Cluster 3r consists of 20 watersheds located at high elevations as indicated by the high percentage of the watersheds in the precipitation snow category (table 2.2). These watersheds also have high to moderate stream gradients and a mainly non-calcareous geology. High gradients, cold temperatures, and low nutrient concentrations are not conducive to high levels of fish production and we would expect these streams to have low standing stocks of coldwater fish species or to be fishless.

Cluster 4r contains watersheds in the middle elevation range but production of coldwater fishes would be limited by high stream gradients and the largely non-calcareous geology (table 2.2). The highest combination of drivers for this cluster (45%) is for non-calcareous geology, precipitation as rain-and-snow, and high stream gradient (CnPrsGh).

Cluster 5r watersheds are similar to those in Cluster 3r in being primarily at high elevations and having high stream gradients, however Cluster 5r watersheds tend to be a mixture of calcareous and non-calcareous geology (table 2.2). Although the calcareous geology would increase nutrient concentrations in some watersheds, we would still expect fish production to be limited because of the cold temperatures and high stream gradients.

Watersheds in **Cluster 6r** are characterized by precipitation as rain, non-calcareous geology and low stream gradients (CnPrGl). In fact, this combination of drivers constitutes 69% of the surface area of these watersheds. This combination of drivers is the least conducive to production of coldwater fishes and native, non-game fishes, especially minnows and suckers, would dominate streams in these watersheds.

Cluster 7r watersheds have some areas as precipitation as rain-and-snow (30%) and snow (5%) and thus could support some coldwater fishes in the upper portions of these watersheds. However, precipitation as rain is the most common category (65%; table 2.2). The geology is largely non-calcareous (75%) and stream gradients are mainly high (45%) or moderate (40%); traits that are not conducive to high levels of fish production.

Cluster 8r contains the lowest elevation watersheds in the study area and is characterized almost exclusively by precipitation as rain (99%, table 2.2). No coldwater fishes would be expected in these watersheds. Watersheds in Cluster 8r are dominated by calcareous geology and low stream gradients and thus should be productive sites for warmwater, non-game fish species.

Cluster 9r watersheds are similar to those in Cluster 8r in being characterized by precipitation as rain and calcareous geology (table 2.2). However, watersheds in Cluster 9r are unusual in having a large portion of streams in the high gradient category (56%). In fact, the combination of calcareous geology, precipitation as rain, and high gradient constitutes 33% of the area in these watersheds. This combination of drivers would result in high gradient, biologically productive, warmwater streams. Such streams are uncommon within the study area.

Management Scale

Riparian Cluster Analysis

Management-scale agglomerative cluster analysis identified six clusters for the 74 6th level HUBs intersecting the Bighorn National Forest boundary; based on a 25% similarity cut point (figs. 2.16 and 2.17). There is a distinct break between Clusters 1-4r and Clusters 5-6r. Clusters 5-6r are located primarily on the Great Plains and therefore at lower elevations, while Clusters 1-4r are located in the higher elevations.

Driver Composition of Individual Riparian Clusters

Both geologic rock types (Ca and Cn) dominate several clusters in this analysis (table 2.3). The relatively high percentage of non-calcareous bedrock associated with Cluster 1r is due to its proximity to the Cloud Peak Wilderness area, which is dominated by igneous bedrock. Clusters 2r, 4r, and 5r, which have high percentages of calcareous bedrock, each have one entire 6th level HUB within the Bighorn National Forest boundary.

Cluster 6r is mostly located on the Great Plains, and is the only cluster dominated by rain-driven hydrology. It is also characterized by non-calcareous bedrock and low gradient streams.

Most of the clusters are associated with high gradient stream channels (Clusters 1-5r). Clusters 2r and 3r exhibit the highest percentage of low gradient stream segments in the mountainous areas, and Cluster 2r also has a high percentage of calcareous bedrock. Overall, low gradient stream channels are not abundant at the management scale, and their associated habitats, communities, and species may be relatively rare.

Table 2.3. Percent area or stream length encompassed by individual ecological drivers for the management-scale riparian and aquatic ecosystem assessment of 74 6th level HUBS intersecting the Bighorn National Forest.

	Percent Area or Length Encompassed by a Specific Ecological Driver							
Riparian	Geology		Climate (precipitation)			Stream Gradient		
Clusters	Ca	Cn	Pr	Prs	Ps	Gh	Gm	Gl
1r	11.37	**88.63**	0.07	21.22	**78.71**	**57.16**	32.33	10.52
2r	**52.57**	47.43	0.46	**46.89**	52.65	**44.68**	34.40	20.92
3r	9.86	**90.14**	17.43	**66.09**	16.49	**50.12**	20.09	29.78
4r	**58.84**	41.16	8.95	21.18	**69.87**	**79.76**	13.20	7.04
5r	**77.13**	22.87	31.34	**53.94**	14.72	**62.00**	18.23	19.78
6r	16.79	**83.21**	**76.61**	20.61	2.78	31.90	28.38	**39.72**

Ca *– calcareous geology,* ***Cn*** *- non-calcareous geology;* ***Pr*** *- rain driven hydrology,* ***Prs*** *– rain-and-snow driven hydrology,* ***Ps*** *- snowmelt driven hydrology,* ***Gh*** *- high gradient stream reaches,* ***Gm*** *– moderate gradient stream reaches,* ***Gl*** *- low gradient stream reaches.*

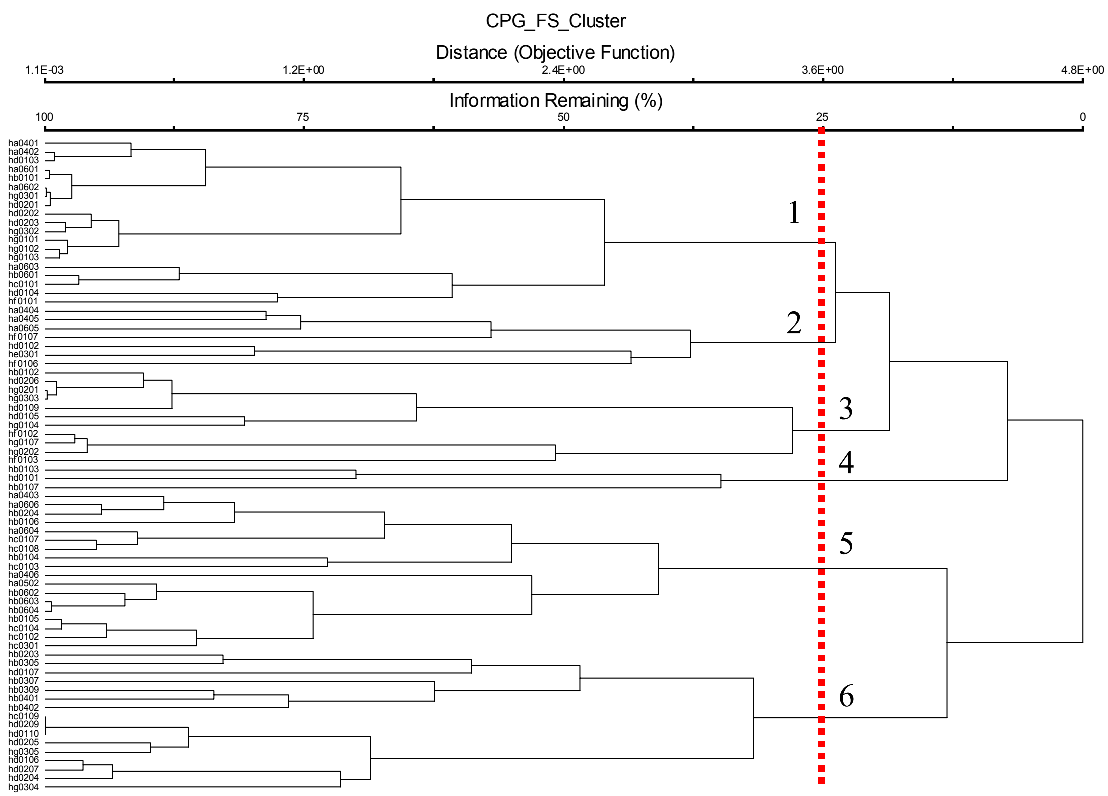


Figure 2.16. Management-scale agglomerative cluster analysis of riparian and aquatic ecosystems using the 74 6th level HUBs that intersect the Bighorn National Forest. Geology, climate (precipitation), and stream gradient drivers produced six distinct clusters. The dashed vertical line indicates the level of similarity or cut point used to define the clusters, and the numbers next to the line denote the clusters discussed in the text.

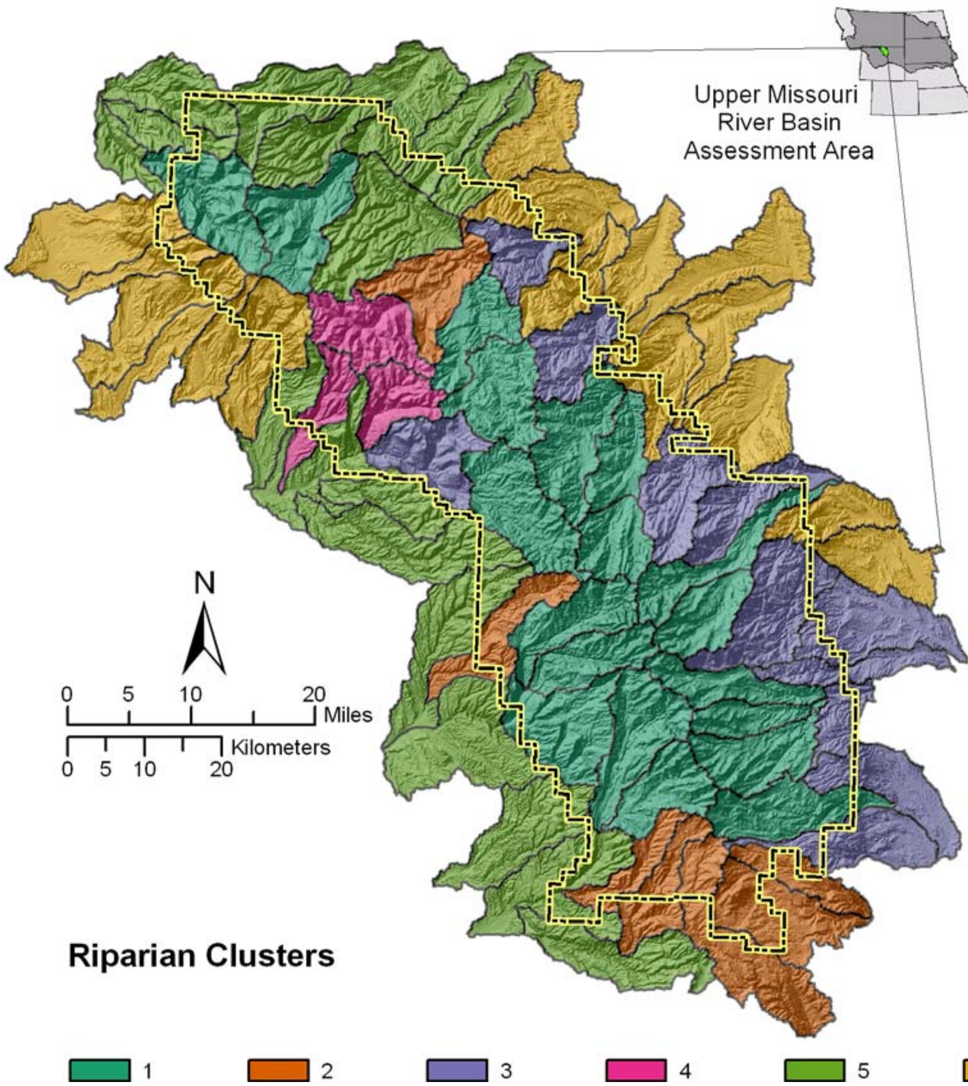


Figure 2.17. Distribution of six cluster groups for riparian and aquatic ecosystems based on management-scale analysis of ecological drivers for 74 6th level HUBs intersecting the Bighorn National Forest. Geology, climate, and stream gradient were the drivers used to produce the six clusters.

The Bighorn National Forest Riparian Inventory

The Bighorn National Forest riparian inventory (Girard et al. 1997) identified five categories: P = ponds, L = lakes and reservoirs, S = riparian areas along streams, M = meadows associated with a drainage or stream that has subsurface drainage, W = wetland located outside of stream channels, including seeps springs and headwater basins. These types are uniquely defined for the Big Horn Mountains. "S" riparian areas are quite similar to riparian areas as defined in Winters et al. (2003a). "Meadows" include wet meadows and marshes, and "wetlands" would include fens, wet meadows, marshes and salt flats (Winters et al. 2003a). In the following analysis we use the "S" type areas classified by Girard et al. (1997) as riparian areas. Areas classified, as "P, L, M, and W" are wetlands and are analyzed in the wetland section of this report.

The mapped riparian areas include jurisdictional wetlands under the Clean Water Act, but some areas would not be jurisdictional wetlands based upon the 1987 Corps of Engineers Wetlands Delineation Manual (Environmental Laboratory 1987). We have used the mapped and classified riparian data set to analyze 6th level HUBs and clusters of HUBs to analyze the influence of physical drivers on the abundance and type of riparian areas occurring in HUBs.

Influence of Physical Drivers on Riparian Areas

Riparian Ecosystem Analysis

The GIS coverage of riparian vegetation for the Bighorn National Forest allows us to analyze the influence of physical drivers on streamside riparian ecosystems. Regression analysis indicated that the percentage of streamside riparian ecosystems within HUBs declines linearly with an increasing percentage of calcareous bedrock in HUBs. This indicates those watersheds with a high proportion of calcareous bedrock support smaller, or fewer, riparian areas. Possible explanations for this pattern include: a) calcareous watersheds occurring at lower elevations and receive less precipitation; b) most calcareous watersheds are not in the highest elevation core of the Big Horn Mountains and were not glaciated, thus they have less suitable landform for supporting extensive riparian area; c) calcareous watersheds may have higher sediment loads leading to smaller areas with suitable water table depths; or d) lower elevation areas have steeper stream gradients, supporting riparian areas of narrower width.

River Physical Form and Function Analysis Including Sediment Dynamics

Using the six clusters differentiated on the basis of the management-scale cluster analysis for the 74 6th level HUBS intersecting the Bighorn National Forest, we added the total length of stream (in miles) in high, moderate, and low gradient segments within each cluster.

High and moderate gradient stream segments dominate the Bighorn National Forest. These types of streams are less sensitive to changes in sediment supply, especially where the underlying geology is calcareous. Calcareous rock types produce less fine sediment clasts (clay to gravel size) that can influence stream substrate and habitat availability.

Invertebrate Diversity and Instream Production Analysis

The ecological drivers used to derive HUB clusters for the assessment of invertebrate diversity and aquatic productivity: climate (precipitation), geology, and stream gradient; are recognized to influence many aspects of aquatic diversity and productivity, which are more fully described in Winters et al. (2003a).

Climate (precipitation regime) in the Bighorn National Forest is a function of elevation, and thus is strongly correlated with temperature and hydrologic regimes. Temperature conditions are critical determinants of the growth and developmental rates of ectothermic invertebrate species (Vannote and Sweeney 1980; Ward and Stanford 1982). Growth rates, development rates, and the timing of emergence of lotic insects is strongly influenced by thermal regime, and hence altitude (Ward 1992). Temperature can also regulate the distribution and abundance of many aquatic insect species within a drainage. Thus, there is a distinct "altitudinal zonation" in Rocky Mountain streams, directly reflecting the thermal conditions prevailing at those altitudes (Hauer and Stanford 1982; Ward 1986; Ward and Kondratieff 1992;). Productivity of aquatic invertebrate communities is generally higher in warmer waters (Ward 1992; Benke 1993), because metabolic rates for ectotherms are increased. Such increases in productivity may not necessarily be transferred up the food chain, however.

The hydrologic regime determines how much water is in the channel at any given time. Drying of streams (intermittency) has severe consequences for aquatic communities, severely reducing diversity and limiting production (Larimore et al. 1959; Stanley et al. 1997). Perennial streams in the Big Horn Mountains are associated with headwaters having heavy snow accumulations and/or springs. Streams that head at lower elevations (e.g., foothills and plains) are likely to be seasonally influenced by runoff from rainfall, which may provide the main source of streamflow. These systems tend to be more temporally intermittent during periods of low precipitation, because they lack the storage characteristic of snowmelt streams. Thus, lower elevation streams may have a very different fauna due to seasonal drying and to late-season disturbance (in addition to other factors, such as warmer summer water temperature).

During high flow events, sediment is transported and this often serves as a source of disturbance that induces mortality in benthic invertebrate populations (Resh et al. 1988; Poff 1992) and scours benthic algae (Peterson 1996; Peterson et al. 2001). The frequency and timing of bed movement influence the types of species that occur in a system. For example, frequently disturbed streams are dominated by highly mobile species that are good at recolonization (Scarsbrook and Townsend 1993; Richards et al. 1996; Townsend et al. 1997a; Robinson and Minshall 1998). Invertebrate diversity can be maximal at intermediate levels of disturbance (Townsend et al. 1997b), possibly because 'weedy species' are not eliminated by superior competitors, which are more severely reduced in abundance by disturbance (Hemphill and Cooper 1983; Hildrew and Giller 1994; Townsend et al. 1997a). Interannual variation in population sizes for lotic species can also be attributed to interannual variation in disturbance or other environmental conditions (Feminella and Resh 1990; Voelz et al. 2000). High flow disturbances also have a direct influence on invertebrate production, because mortality reduces population size and thus biomass.

Geology regulates the types of sediments produced by bedrock weathering and the quantities of nutrients available for dissolution and transport to streams. Bedrock type also influences rates and pathways of runoff to stream channels, thereby regulating stream thermal and flow regimes. These factors individually and interactively influence invertebrate production and diversity. For example, substrate size composition and heterogeneity dictate habitat diversity and interstitial living space, both of which exert some control on invertebrate communities (Minshall 1984). Coarse-grained gravel bedded streams typically have greater production than fine-grained or silty channels (Allan 1995; Waters 1995). The geochemical composition of the watershed also regulates invertebrate production, which is generally higher in streams draining calcareous versus granitic lithology, due to a combination of greater dissolved nutrients and more stable thermal and flow regimes (Krueger and Waters 1983; Huryn et al. 1995). This effect may be enhanced at very high elevation, where cold temperature may interact with low nutrient to further limit invertebrate production potential.

Stream gradient is a very important control on both invertebrate production and diversity. Furthermore, the influence of gradient manifests itself not only locally but also in a broader, landscape sense. For example, stream reaches are hydrologically connected, and the flux of materials, energy, and organisms through the stream network is dictated by variation in local gradients. Lower gradient reaches tend to retain more sediment and dissolved nutrients and thus have greater habitat complexity and local production. For example, invertebrate production tends to be higher in lower vs. higher gradient reaches (Huryn and Wallace 1987). Higher gradient reaches tend to be laterally confined and thus convey more energy during flood flows, which cause mortality of benthic invertebrates and/or reduce aquatic production (Poff and Huryn 1998).

Lower gradient reaches of mountain streams may also have more varied thermal regimes due to hyporheic flow patterns. For example, Baxter and Hauer (2000) found that much of the water flowing out of constrained canyon reaches into low gradient alluvial reaches entered the fine subsurface sediments in the alluvial reaches as hyporheic flow. Toward the foot of the alluvial reach, the subsurface water emerged as the stream entered another bedrock-controlled canyon reach. Hyporheic flow provides winter thermal refugia for invertebrates (Stanford and Ward 1988) and fish (Baxter and Hauer 2000) and can also promote nutrient transformations that make dissolved organic N available to primary producers as dissolved NO_3^- (Grimm 1987).

The higher relative production of low gradient stream reaches has important implications for production and diversity not only locally, but in steeper downstream stream reaches as well. Given the largely unidirectional nature of streamflow (especially in montane settings), nutrients and food resources are typically transported downstream (stream spiraling – Webster and Patten 1979). Low gradient reaches retain sediment and develop geomorphic complexity that promotes local establishment of deciduous riparian communities, which can export leaf material and wood into the channel (Gregory et al. 1991). This material provides habitat and food resources for benthic invertebrates, many of which may enter the drift and fuel downstream food chains (Allan 1995).

Fisheries Analysis

Relative to the other aquatic ecoregions of North America, the Upper Missouri River ecoregion is characterized by low fish species richness and few endemic species (Abell et al. 2000). Because most fish species are generally widespread and occur in other ecoregions, the proportion of fish species considered imperiled is low in the Upper Missouri River ecoregion (Abell et al. 2000). An exception involves several subspecies of cutthroat trout that are considered to be a conservation concern by states in the region. These include Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* and westslope cutthroat trout *Oncorhynchus clarki lewisi* (Gresswell 1988).

There are eleven fish taxa that occur within the boundary of the Bighorn National Forest (table 2.4). Members of the family Salmonidae dominate the fish fauna with the only other types of fish present being one species of sucker (family Catostomidae) and one species of minnow (family Cyprinidae). Only two of the eleven fish taxa are native to the Bighorn National Forest: the mountain sucker and the Yellowstone cutthroat trout. Most of the remaining taxa were introduced for sport fishing purposes and have subsequently established self-reproducing populations. Both fish species native to the Bighorn National Forest are of conservation concern. The Yellowstone cutthroat trout is considered a sensitive species by the states of Idaho, Montana, and Wyoming, and by the Northern and the Rocky Mountain Region of the United States Forest Service (Young 1995). This subspecies of cutthroat trout was petitioned for listing as federally threatened, but the U.S. Fish and Wildlife determined that listing was not warranted as of 2001 (Federal Register 2001). The mountain sucker *Catostomus platyrhynchus* has a Nature Conservancy conservation status of N4 in the United States, which means it is considered "apparently secure" (http://www.natureserve.org/explorer). However, mountain suckers are considered a species of conservation concern in Region 2 of the U.S. Forest Service.

Lower elevation portions of the 4th level HUBs that originate on the Bighorn National Forest contain a more diverse assemblage of fish species than is found within the Forest. Fish assemblages at these lower elevations are dominated by native warmwater species in the minnow (Cyprinidae), sucker

(Catostomidae), and catfish (Ictaluridae) families (table 2.5). Nonnative species are primarily from the sunfish family (Centrarchidae) and were introduced as sportfish (Baxter and Stone 1995). These include largemouth bass, rock bass, smallmouth bass, and white crappie. One of the native minnows, the flathead chub *Platygobio gracilis*, is listed as a sensitive species for Region 2 of the U.S. Forest Service. However, this species has a Nature Conservancy global conservation status of G5 which means that it is considered "secure" (http://www.natureserve.org/explorer/) and the species is not listed as sensitive within the states of Wyoming or Montana (Wyoming Natural Diversity Database; http //uwadmnweb.uwyo.edu/WYNND/Fish). Another species, the sturgeon chub *Macrhybopsis gelida*, is not listed as a sensitive species by Region 2 of the U.S. Forest Service but is considered a regionally sensitive species by the Nature Conservancy with a conservation status of critically imperiled (S1) in Wyoming and imperiled (S2) in Montana (http://www.natureserve.org explorer).

Three of the 4th level HUBs that originate on the Bighorn National Forest are part of the Powder River system; Clear Creek, Crazy Women Creek, and the Middle Fork of the Powder River. The Powder River is an 800-km long tributary of the Yellowstone River and is a turbid, saline, meandering system with a highly braided, and unstable sand-bottom channel. It is a relatively unique system in that it has not been impounded and thus represents a free flowing, turbid, prairie stream with a largely intact native fish fauna (Hubert 1993). Of the 32 fish species known to occur in the Powder River, 25 are native, including several taxa of national or regional conservation concern such as the shovelnose sturgeon *Scaphirhynchus platorynchus*, the sturgeon chub, and the flathead chub. Hubert (1993) identified the Powder River as a relatively pristine Great Plains stream worthy of conservation attention because of its unmodified habitat and largely native fish assemblage. He emphasized the importance of protecting tributary habitats because many native fishes in the Powder River are highly migratory and utilize tributaries as spawning habitat or as a seasonal refuge from harsh abiotic conditions in the main stem river.

Table 2.4. Fish families and species found within the Bighorn National Forest. Status refers to whether the species was historically native to the Bighorn National Forest. Naturalized means that introduced populations of these nonnative species now reproduce and have become self-sustaining in parts of the Forest. Stocked means that populations have been introduced, but do not naturally reproduce.

Species	Scientific name	Status	Comments
FAMILY: Salmonidae (salmon and trout)			
Yellowstone cutthroat trout	*Oncorhynchus clarki bouvieri*	native	
Snake River cutthroat trout	*Oncorhynchus clarki sp.*	nonnative	naturalized
Rainbow trout	*Oncorhynchus mykiss*	nonnative	naturalized
Golden trout	*Oncorhynchus aguabonita*	nonnative	naturalized
Brook trout	*Salvelinus fontinalis*	nonnative	naturalized
Lake trout	*Salvelinus namaycush*	nonnative	naturalized
Splake	brook trout-lake trout hybrid	nonnative	stocked
Brown trout	*Salmo trutta*	nonnative	naturalized
Grayling	*Thymallus arcticus*	nonnative	naturalized
FAMILY: Catostomidae (suckers)			
Mountain sucker	*Catostomus platyrhynchus*	native	
FAMILY: Cyprinidae (minnows)			
Lake chub	*Couesius plumbeus*	nonnative	naturalized

Table 2.5. Fish families and species present (denoted by X) at lower elevations outside the Bighorn Forest in 4th level HUBs drainages that originate on the Forest. Status refers to whether the species is native (N) or introduced (I) to the Missouri River drainage in Wyoming. Data are from Patton (1997).

Species	Scientific name	Status	Upper Tongue River	Powder River drainages[1]	Big Horn River drainages[2]
Hiodontidae (mooneyes)					
Goldeye	*Hiodon alosoides*	N		X	
Cyprinidae (minnows)					
Brassy minnow	*Hybognathus hankinsoni*	N		X	
Creek chub	*Semotilus atromaculatus*	N	X	X	
Carp	*Cyprinus carpio*	I	X	X	X
Flathead chub	*Platygobio gracilis*	N	X	X	X
Fathead minnow	*Pimephales promelas*	N	X	X	X
Lake chub	*Couesius plumbeus*	N	X		X
Longnose dace	*Rhinichthys cataractae*	N	X	X	X
Plains minnow	*Hybognathus placitus*	N		X	
Sand shiner	*Notropis stramineus*	N	X	X	
Sturgeon chub	*Macrhybopsis gelida*	N		X	
Catostomidae (suckers)					
Longnose sucker	*Catostomus catostomus*	N	X	X	X
Mountain sucker	*Catostomus platyrhynchus*	N	X	X	X
Northern redhorse	*Moxostoma macrolepidotum*	N	X	X	X
River carpsucker	*Carpiodes carpio*	N		X	
White sucker	*Catostomus commersoni*	N	X	X	X
Ictaluridae (catfish)					
Black bullhead	*Ameiurus melas*	N	X		
Channel catfish	*Ictalurus punctatus*	N		X	
Stonecat	*Noturus flavus*	N	X	X	X
Cyprinodontidae (killifish)					
Plains killifish	*Fundulus zebrinus*	N		X	
Centrarchidae (sunfish)					
Largemouth bass	*Micropterus salmoides*	I			X
Rock bass	*Ambloplites rupestris*	I	X	X	
Smallmouth bass	*Micropterus dolomieui*	I	X	X	
White crappie	*Pomoxis annularis*	I	X		
Percidae (perch)					
Yellow Perch	*Perca flavescens*	I			X

[1]*Powder River 4th level HUBs include Clear Creek, Crazy Women Creek, and Middle Fork of the Powder River.*
[2]*Big Horn River 4th level HUBs include the Nowood River, Big Horn Reservoir, and the Little Big Horn River systems.*

The three large-scale environmental factors or “drivers”, geology, precipitation, and stream gradient, were considered to have a major influence on the distribution and abundance of fishes in the Bighorn National Forest. Geology influences coarse scale patterns of water fertility and susceptibility to acid precipitation. The abundance of calcareous rocks influences stream alkalinity, a measure of nutrient content often correlated with the abundance of aquatic organisms (Krueger and Waters 1983; Kwak and Waters 1997). The abundance of calcareous rocks also determines the sensitivity of aquatic systems to cultural acidification because carbonate and bicarbonate ions help buffer against the effects of elevated hydrogen ions in acid precipitation (Haines 1981).

The precipitation categories reflect thermal conditions, which in turn, determine the type of fish species likely to occur. For example, the coldwater fish guild is not likely to persist in the Rocky Mountain Region in areas where mean July air temperatures exceed 22°C (Keleher and Rahel 1996). Various species of trout may have distributions defined by thermal envelopes. For example, the geographic distribution of brown trout in eastern Wyoming was limited to a thermal envelope defined by mean July air temperatures of 19-22°C with higher elevations dominated by brook trout and lower elevations dominated by minnows and suckers (Rahel and Nibbelink 1999). Streams in the Rocky Mountains show a characteristic transition from dominance by various species of trout in headwaters to dominance by minnows and suckers at lower elevations because of a general inverse relationship between elevation and temperature (Rahel and Hubert 1991).

Stream gradient is important because it influences the types of habitat units present (e.g., riffles, pools, and cascades) and substrate characteristics. High gradient reaches are dominated by riffles or cascade habitats, whereas runs and pools dominate low gradient reaches. In general, low gradient reaches are more conducive to fish production and are especially important areas for larger individuals that are typically associated with deep pool habitats (Chisholm and Hubert 1986). In some cases, high stream gradients can prevent fish from colonizing or maintaining populations in streams (Kruse et al. 1997).

The three drivers used in the cluster analysis were chosen because many scientific studies have shown them to influence fish assemblage characteristics and aquatic productivity (Winters et al. 2003a). However, because the influence of drivers can vary among ecoregions or can be modified by local habitat conditions, it would be insightful to evaluate the results of the cluster analysis by comparing predicted fish assemblage characteristics with data from fisheries surveys. Such an analysis also would provide insights into areas where special fishing regulations might be most beneficial or where re-introductions of native species would be most feasible.

Ecological Importance of Riparian Clusters at the Management Scale

Cluster 1r

HUBs in **Cluster 1r** are primarily non-calcareous, snowmelt driven, with high gradient streams as would be expected for the highest elevations within the Big Horn Mountains (fig. 2.17).

Riparian Ecosystem Analysis

The hard igneous and metamorphic rock that forms the core of the range is exposed in this area, producing relatively little sediment and low ion concentrations in surface and groundwater. This cluster has the second highest percentage of riparian areas (5.77%). Consequently, HUBs in this cluster will be highly sensitive to changes in their hydrologic and sediment regimes because they support significant riparian areas.

Sediment Dynamics Analysis

Increased or decreased sediment supply is likely to have little influence on step-pool channels within **Cluster 1r**, but may result in channel change for the lower gradient streams. The high gradient streams are not likely to be sensitive to increased flow, but may lose pool volume (which is already relatively low in step-pool channels) as a result of decreased flow. Pool volume in the lower gradient streams will be more sensitive to changes in flow.

Invertebrate Diversity and Instream Production Analysis

Streams in **Cluster 1r** are dominated by snow hydrology, by non-calcareous geology, and comprise the highest elevation HUBs in the Forest. Thus, they are perennial, coldwater streams and have primarily steep stream channels. As such, Cluster 1r will support cold-adapted fauna and flora, and productivity will be generally low compared to perennial streams at lower elevations. However, within this cluster the presence of low gradient stream channels indicates some alluvial features (high mountain valleys) where local production and diversity are likely to be locally high due to relatively reduced stream energy and enhanced nutrient and organic matter retention. In general, we expect to see the "typical" high mountain biota (Ward 1986).

Fisheries Analysis

Streams in **Cluster 1r** would be extremely cold and unproductive. This is the driver combination least conducive to fish production and high gradients may have limited even the presence of fish historically.

Cluster 2r

HUBs in **Cluster 2r** occur north and south of the main range core, and have either calcareous or non-calcareous bedrock, snow or rain-and-snow precipitation regime, and high and moderate gradient streams (fig. 2.17).

Riparian Ecosystem Analysis

Cluster 2r is a heterogeneous group of HUBs, with a wide diversity and large percentage of riparian area. It also has the highest percentage of each HUB that is riparian habitat (table 2.6). Because such a large area is riparian, these areas will be highly susceptible to changes in surface water flow patterns.

Table 2.6. Management scale analysis of riparian area within the six clusters. Area (acres) of HUBs within the six clusters, number (N) of HUBs within each cluster, total area of riparian ecosystems in cluster, and mean percent of each HUB that is riparian.

Riparian Clusters	HUB Area	HUBs (N)	Riparian Area	Percent HUB as Riparian
1r	505,958	19	29,181	5.77
2r	106,725	7	6,221	5.83
3r	188,304	11	10,673	5.67
4r	58,037	3	1,863	3.21
5r	175,171	18	6,171	3.52
6r	78,200	16	3,704	4.74

Sediment Dynamics Analysis

Streams in **Cluster 2r** are likely to respond to changes in water and sediment supply as described for Cluster 1r, but may be less sensitive to changes in sediment where calcareous geology is present.

Invertebrate Diversity and Instream Production Analysis

Cluster 2r contains what appear to be a heterogeneous set of HUBs in terms of precipitation type, bedrock geology, and stream gradient composition. Given this heterogeneity, we expect habitat heterogeneity and production potential to be relatively high in this cluster. However, further interpretation would require more spatially explicit analysis of the distribution of habitat types within these HUBs.

Fisheries Analysis

Watersheds in **Cluster 2r** are noteworthy for the diversity of driver combinations they contain. There is a mix of geology and stream gradients present in these watersheds that are located mainly at high elevations, although not as high as watersheds in Clusters 1r and 4r (fig. 2.17). Watersheds in this cluster should have a mix of habitat conditions and abundant coldwater fish populations, especially in areas with calcareous geology and moderate to low gradients. Of all the clusters, Cluster 2r has the highest proportion (11%) of the driver combinations most conducive to coldwater fish production (e.g., calcareous geology, precipitation as rain-and-snow, and streams gradients either moderate or low). These driver combinations are relatively rare in the Bighorn National Forest and are important areas for coldwater fisheries.

Cluster 3r

HUBs in **Cluster 3r** occur primarily on the eastern side of the Big Horn Mountains, in foothill locations, have non-calcareous bedrock and high gradient streams. HUBs in Cluster 3r occur just east of HUBs in Cluster 1r, at lower elevation, and with a primarily rain-and-snow precipitation regime (fig. 2.17).

Riparian Ecosystem Analysis

A comparatively high percentage of the total HUB area of **Cluster 3r** is riparian (5.67%). Riparian areas in these HUBs are extremely sensitive to changes in surface water flows because of their close association with stream corridors.

Sediment Dynamics Analysis

Cluster 3r streams are moderately sensitive to changes in sediment, but less sensitive to changes in flow because of the influence of rainfall runoff.

Invertebrate Diversity and Instream Production Analysis

Streams in **Cluster 3r** are at mid-elevation, as indicated by the predominant rain-and-snow precipitation regime. They also tend to have a slight dominance of steep channels. Streams here should have relatively high production and diversity compared to the high elevation Clusters 1r and 4r, as they are not as thermally harsh. Again, low gradient reaches within HUBs should be more productive and have higher invertebrate diversity. Cluster 3r is almost entirely non-calcareous, although about 6% of all stream channels in this cluster are CaPrsGh. Additionally, HUBs comprising Cluster 3r lie primarily on the eastern flank of the Forest.

Fisheries Analysis

Cluster 3r watersheds are on the eastern edge of the Bighorn Forest and are dominated by non-calcareous geology (table 2.3), which would limit aquatic productivity and hence fish biomass.

Cluster 4r

HUBs in **Cluster 4r** occur at high elevation on the northern side of the range, are underlain by calcareous bedrock in most areas, have a snowmelt hydrological regime, and have high gradient streams (fig. 2.17).

Riparian Ecosystem Analysis

The HUBs in **Cluster 4r** have a low acreage of riparian area due to the high gradient landscape that leads to rapid runoff of water. These areas were not glaciated and do not have the proper habitat template to form riparian habitats. These HUBs have the lowest percentage of riparian communities, indicating that most valleys have intermittent streams with little riparian vegetation.

Sediment Dynamics Analysis

The relative lack of fine sediment produced by weathering calcareous rocks would make the high gradient streams in **Cluster 4r** insensitive to changes in sediment supply.

Invertebrate Diversity and Instream Production Analysis

Streams in **Cluster 4r** are dominated by snow hydrology and comprise the highest elevation HUBs in the Forest. Thus, they have perennial, coldwater streams and have primarily steep stream channels. Cluster 4r will support cold-adapted fauna and flora and productivity will be generally low compared to perennial streams at lower elevations. However, within Cluster 4r, the presence of low gradient stream channels indicates some alluvial features (high mountain valleys) where local production and diversity are likely to be locally high due to relatively reduced stream energy and enhanced nutrient and organic matter retention. In general, we expect to see the "typical" high mountain biota (Ward 1986).

The distinction between Clusters 1r and 4r is that Cluster 1r is dominated primarily by non-calcareous geology, whereas Cluster 4r has mostly calcareous geology (table 2.3). We therefore expect a higher potential aquatic productivity in Cluster 4r compared to Cluster 1r, holding other factors such as stream gradient constant. However, this distinction in production is problematic, since Cluster 4r has more high gradient streams than does Cluster 1r. Furthermore, Cluster 4r consists of only three HUBs (compared to the 17 in Cluster 1r), so this cluster may deserve special management attention, especially in the low gradient reaches of the constituent HUBs (which comprise only about 2% of the total stream length), because potential production and diversity should be maximal in these reaches.

Fisheries Analysis

Cluster 4r consists of three watersheds that are unusual in being dominated by calcareous geology, precipitation as snow, and high stream gradients. Streams should contain coldwater fish species but the cold temperatures and high gradients would limit fish production.

Cluster 5r

HUBs in **Cluster 5r** occur at the mountain front on the western and northern sides of the Big Horn Mountains. Their watersheds are largely calcareous, with rain-and-snow precipitation regimes and high gradient streams (fig. 2.17).

Riparian Ecosystem Analysis

Cluster 5r has the second lowest area of riparian ecosystems. Nearly 81% of all riparian ecosystems in this cluster occur along streams, indicating a lack of groundwater-fed wetlands.

Sediment Dynamics Analysis

The high gradients and lack of fine sediment in **Cluster 5r** makes these streams less sensitive to changes in sediment supply.

Invertebrate Diversity and Instream Production Analysis

Streams in **Cluster 5r** are at mid-elevation, as indicated by the predominant rain-and-snow precipitation regime. Cluster 5r also tends to have a slight dominance of steep channels. Streams in Cluster 5r should have relatively high production and diversity compared to high elevation Clusters 1r and 4r, as they are not as thermally harsh. Again, low gradient reaches within HUBs should be more productive and have higher invertebrate diversity.

The distinction among Clusters 3r and 5r lies in the bedrock geology. Cluster 3r is almost entirely non-calcareous, although about 6% of all stream channels in this cluster are CaPrsGh. By contrast, Cluster 5r is dominated by calcareous bedrock, with about 44% and 10% of all stream channels comprised of CaPrsGh and CaPsGh, respectively. Thus, we would expect *average* aquatic production and diversity to be higher in HUBs of Cluster 5r than of Cluster 3r. Again, however, spatial variation within HUBs (e.g., in terms of local gradient) will be important. Additionally, HUBs comprising Cluster 3r lie primarily on the eastern flank of the Forest, whereas HUBs in Cluster 5r are to the north and west. This difference in aspect may be important for aquatic resources via: 1) zoogeographic constraints on fish distribution; 2) indirect effects mediated by riparian conditions; and 3) potential hydrologic processes resulting from solar radiation and upland vegetation structure.

Fisheries Analysis

Watersheds in **Cluster 5r** are at the transition between the Big Horn Mountains and the surrounding prairie. These watersheds have precipitation primarily as rain-and-snow or rain, and the predominance of high to moderate stream gradients suggest they span a large elevation range from the mountains to the prairie. In this sense they are similar to watersheds in Cluster 3r. However they differ from watersheds in Cluster 3r by being dominated by calcareous geology, which would enhance aquatic productivity. Watersheds in Cluster 5r should have water temperatures that would support abundant coldwater fish populations, especially in areas of moderate or low stream gradient. In fact the driver combinations most conducive to coldwater fish production (e.g., calcareous geology, precipitation as rain-and-snow, and low or moderate stream gradients) constitute 8% of the area of these drainages. This is second only to Cluster 2r (11%) in terms of the proportion of total stream length having conditions most suitable for coldwater fish production. At lower elevations within these watersheds, streams likely would have more diverse fish assemblages that include non-game fishes such as suckers (family Catostomidae) and minnows (family Cyprinidae).

Cluster 6r

Watersheds in **Cluster 6r** are the lowest elevation watersheds associated with the Bighorn National Forest and much of their area lies outside the Forest boundary. They are dominated by non-calcareous geology and precipitation as rain with much of the stream length in low-gradient reaches. They occupy low elevation areas on the far eastern and northwestern portion of the mountain range (fig. 2.17).

Riparian Ecosystem Analysis

The majority of each HUB in **Cluster 6r** is outside the Bighorn National Forest boundary, and it is impossible to evaluate, based on existing riparian data, which only covers the National Forest. The foothills portions of HUBs within the Bighorn National Forest likely have lower proportions of riparian areas than the plains areas where the gradient is lower. The foothills riparian areas would also likely have plant communities that are very similar to plains communities, with a dominance of plains cottonwood (*Populus deltoids*), sandbar willow *(Salix exigua*), and other species.

Sediment Dynamics Analysis

Cluster 6r contains a mix of stream gradients. These stream segments occur at the lowest elevations, and are dominated by rainfall runoff and non-calcareous rocks. The combination of lower stream gradients, non-calcareous rocks that weather to produce more abundant fine sediment, and a flashier discharge regime would likely make these streams the most sensitive to changes in water and sediment supply.

Invertebrate Diversity and Instream Production Analysis

Productivity and diversity are probably lowest in **Cluster 6r**, due to the harsh environmental conditions of intermittent flow and warm summer temperatures. (However, we expect exceptions for streams that head in the mountains and flow through these HUBs). The largely non-calcareous bedrock should further limit productivity. Production and diversity within this cluster should be highest in low gradient stream segments.

Fisheries Analysis

Streams that originate within **Cluster 6r** likely would be warmwater systems not conducive to coldwater fish production. However, larger streams that originate in higher elevation watersheds would still provide thermally-suitable habitat for coldwater fishes. Streams in the watersheds of Cluster 6r should have the most diverse fish assemblages that include both introduced coldwater game species and native warmwater nongame species. Smaller streams may experience intermittency, which would limit the number and types of fish species that could persist in these systems.

Context to Management Including Sensitivity

Riparian Ecosystem Analysis

Riparian ecosystems are tied to the hydrologic, sediment, and disturbance regime of flowing water. Many plant species reproduce only following flood disturbances. Thus, maintaining the hydrologic regime is of utmost importance for maintaining the integrity of riparian plant communities. Riparian plants likely are relatively insensitive to changes in water temperature, thus the variable thermal regime is not evaluated. Changes in sediment load in stream channels may lead to down cutting or lateral erosion, destroying floodplains and their water-table depth relationships. Sediment deposition from hill slopes can fill riparian areas and provide suitable sites for upland and exotic plant invasion. Riparian areas are typically provided with sufficient nutrients for plant growth, and excessive nutrient supply could benefit exotic plants the most. Exotic plant invasion is relatively unlikely in high elevation HUBs, but is very high at locations below ~9,000 ft elevation because of a greater abundance of exotic plant species (table 2.7).

Table 2.7. Relative sensitivity of riparian ecosystems to changes in hydrologic and thermal regime, sediment and nutrient input, and to nonnative biota. The sensitivity scale ranges from completely insensitive or not applicable (0) to very sensitive (***).

Riparian Clusters	Hydrology	Sediment	Thermal	Nutrient	Biota
1r	***	**	0	*	*
2r	***	**	0	*	*
3r	***	**	0	*	**
4r	***	**	0	*	**
5r	***	***	0	*	***
6r	***	***	0	*	***
Hydrology: Reduced stream peak flows would reduce establishment of woody riparian plants.					
Sediment: Decreased sediment flux from dams may lead to down cutting, and floodplain erosion, increased sedimentation from hill slopes could lead to the formation of communities supporting more upland plants.					
Thermal: NA.					
Nutrients: Nutrients are generally abundant in riparian areas due to high turnover.					
Biota: Nutrients can increase the risk of exotic plant invasion, as well as their abundance on floodplains, especially at lower elevations. Increased sensitivity at lower elevations are due to the presence of exotic plant species only at low elevations.					

River Physical Form and Function Analysis including Sediment Dynamics

Sensitivity to changes in sediment supply increases at lower stream gradients where pool-riffle channel morphology is more likely to be present. Increased fine sediment preferentially accumulates in pools, altering habitat availability and quality. Decreased fine sediment is more likely to result in stream erosion because annual high flows are more capable of eroding the channel boundaries along lower gradient pool-riffle channels than along high-gradient step-pool channels. Sensitivity to changes in sediment supply also increases where geology is non-calcareous because these rock types produce greater volumes of sand and gravel.

All of the channel types present in the Bighorn National Forest are relatively sensitive to changes in hydrologic regime because the watersheds are fairly small, and thus have a greater proportion of surface runoff and lower subsurface water storage than relatively large, lowland drainage basins. Low-gradient stream segments should be slightly less sensitive to changes in hydrologic regime, because flow in these segments is likely to have a greater input from subsurface water. However, flow-dependent habitat characteristics (e.g., pool volume) in low gradient streams are likely to be more sensitive to changes in hydrologic regime in lower gradient streams, because these streams will have greater pool volume compared with high or moderate gradient streams. The relative sensitivity of streams within each cluster to changes in hydrology and sediment is indicated in Table 2.8.

Sensitivity to hydrology was evaluated based on gradient (higher gradient streams have less pool volume and greater boundary resistance, and are thus less sensitive to changes in flow) and flow regime (channels in snowmelt regimes are adjusted to longer duration flows, and may therefore be more sensitive to changes in flow than are rainfall-runoff channels). Sensitivity to sediment was based on gradient (higher gradients streams flush excess sediment and resist erosion when sediment is reduced, and are therefore less sensitive to changes in sediment) and rock type (calcareous streams are less sensitive to changes in sediment supply because these streams are less likely to have substantial changes in fine sediment input).

Table 2.8. Relative sensitivity of stream channels to changes in hydrologic regime and sediment supply. The sensitivity scale ranges from completely insensitive or not applicable (0) to very sensitive (***). Changes in the thermal regime, nutrient input, and nonnative biota do not apply to sediment dynamics.

Riparian Clusters	Hydrology	Sediment
1r	**	*
2r	***	**
3r	***	**
4r	**	0
5r	***	*
6r	***	***

High and moderate gradient stream segments are less sensitive to disturbance, because of the higher boundary resistance associated with coarser sediments. These stream types are often referred to as transport reaches (Montgomery and Buffington 1997); excess sediment is likely to be moved, without substantial channel change, to lower gradient stream segments. Lower gradient streams may be response reaches where excess sediment preferentially fills pools or causes widespread channel aggradation. Higher gradient streams also generally show less response to decreased flow, such as conditions associated with drought or flow diversion. However, high and moderate gradient stream types can undergo substantial change in response to episodic disturbances such as landslides or debris flows, or anthropogenic activities that mimic these effects.

In general, the lower the stream gradient and the finer the channel sediment size, the more responsive and sensitive to disturbance will be the stream. Although the majority of stream reaches within the Bighorn National Forest are relatively insensitive, transport types, the localized lower gradient response reaches (such as pool-riffle, sand- to gravel-bed channels in alpine meadows) can be highly sensitive to disturbance. In addition, the sediment passed downstream through transport reaches may cause substantial channel alteration in the lower gradient stream reaches surrounding the Forest.

Invertebrate Diversity and Instream Production Analysis

In Clusters 1r and 4r the streams are both generally insensitive to sediment additions, because they are high gradient, low response channel types (table 2.9). However, low-gradient segments (e.g., mountain valley reaches), which are likely to be highly productive and diverse, would be vulnerable to sediment additions. Hydrologic alterations, such as water diversion, can have a large effect on small, steep-gradient streams, especially if they are shallow and bedrock-controlled. These high mountain streams will support some unique, cold-adapted invertebrate species (Ward 1986); therefore, an increase in thermal regime (e.g., due to climate change) would be expected to diminish available cold-water habitat for these species. Overall invertebrate production might, however, increase in response to warmer water temperatures. Both these stream types are likely nutrient limited, and thus probably sensitive to nutrient additions. However, Cluster 1r streams, with a non-calcareous geology, could be considered more responsive to the same nutrient input concentrations of Cluster 4r.

Table 2.9. Relative sensitivity of stream productivity to changes in hydrologic and thermal regime, sediment and nutrient input, and to nonnative biota. The sensitivity scale ranges from completely insensitive or not applicable (0) to very sensitive (***).

Riparian Clusters	Hydrology	Sediment	Thermal	Nutrient	Biota
1r	***	**	***	***	***
2r	***	**	**	***	**
3r	***	**	**	***	0/*
4r	***	*	***	**	**
5r	***	**	**	**	0/*
6r	0/*	***	0/*	***	0/*

The sensitivity of Cluster 2r is difficult to assess because habitat heterogeneity is predicted to be high. Cluster 2r is primarily snow and rain-and-snow hydrology, and streams in this cluster might be vulnerable to diversion that converts permanent streams to intermittent ones, with a subsequent large change in biological composition. A warming of current cold-water temperatures might eliminate certain cold-adapted invertebrate species; however, overall invertebrate production might increase.

Clusters 3r and 5r are mid-elevation clusters and are potentially sensitive to hydrologic alteration, particularly a shift from snow and rain-and-snow to rainfall as the dominant form of precipitation (as could happen under climatic warming). A change in water temperature per se would probably enhance invertebrate production. Invertebrate diversity, however, might not be sensitive to thermal enhancement. Cluster 3r streams, with a non-calcareous geology, could be considered more responsive to the same nutrient input concentrations compared to Cluster 5r streams, which drain watersheds comprised largely of calcareous bedrock.

Streams in Cluster 6r could be considered sensitive to increased sediment storage due to overall low gradient. Channel aggradation or siltation generally reduces habitat quality for benthic invertebrates and results in lower productivity and diversity (Waters 1995). This cluster might also be vulnerable to diversion, and permanent streams that became intermittent would probably exhibit large changes in biological composition. Addition of nutrients to streams in this cluster would probably greatly enhance algal production, possibly nuisance algae, given the high residence time of water in these low gradient channels. Warmer temperatures in streams of this cluster would probably not affect the resident warm-adapted fauna.

Fisheries Analysis

The six groups of 6th level HUBs identified by the management-scale cluster analysis will differ in how their fishery resources respond to changes in hydrology, thermal conditions, sediment inputs, nutrient additions, and biotic alterations associated with introduced species (table 2.10).

Table 2.10. Relative sensitivity of fishery resources to changes in hydrologic and thermal regime, sediment and nutrient input, and to nonnative biota. The sensitivity scale ranges from completely insensitive or not applicable (0) to very sensitive (***).

Riparian Clusters	Hydrology	Sediment	Thermal	Nutrient	Biota
1r	**	*	0	***	***
2r	**	*	*	*** or **	***
3r	***	**	**	***	***
4r	**	*	0	**	***
5r	***	**	**	**	***
6r	***	***	***	***	*

Cluster 1r watersheds are at the highest elevations in areas of non-calcareous geology and have high gradient streams. Because these are headwater watersheds, most streams will be small and strongly influenced by snowmelt flow regimes. The small size of most streams means they are sensitive to reductions in streamflow associated with water diversion activities. Streams in these watersheds are coldwater systems and may even be too cold to support fish in some cases (Mullner 2001). Warming of streams due to loss of forest canopy or global climate change would not be sufficient to cause the loss of coldwater fishes and might allow populations of these species to expand to higher elevations. Increased sediments would likely be moved through the systems because of the high stream gradients. However, sediments would accumulate in the few stream reaches that are low gradient. These typically are mountain meadow environments that support high abundances of fish. Nutrient additions could impact Cluster 1r watersheds because the non-calcareous geology produces naturally low nutrient conditions in streams. Fish assemblages in both Cluster 1r watersheds would be susceptible to invasion by nonnative coldwater fishes. Historically, this has involved brook trout that thrive in small, high elevation streams in the western U.S. and often displace native cutthroat trout (Novinger and Rahel 2003).

Watersheds in Cluster 2r also are at high elevations although not as high as those in Clusters 1r and 4r (fig. 2.17). Streams in Cluster 2r watersheds also would be sensitive to summer reductions in streamflow associated with water diversion activities. Streams in Cluster 2r watersheds are coldwater systems but not likely to be too cold to support fish. Warming of streams due to loss of forest canopy or global climate change would not be sufficient to cause the loss of coldwater fishes and would likely increase fish production. Increased sediments likely would be moved through the systems because of the high stream gradients. However, sediments would accumulate in the approximately 21% of stream reaches that are low gradient (table 2.3). These typically are mountain meadow environments that support high abundances of fish. Because Cluster 2r watersheds are a mixture of calcareous and non-calcareous geology (table 2.3), the effects of nutrient additions would depend on local geology. Approximately 29% of the area in Cluster 2r watersheds is in the non-calcareous, precipitation as rain, high or medium gradient categories and these areas would respond similarly to Cluster 1r watersheds to sediment and nutrient inputs. Fish assemblages in Cluster 2r would be susceptible to invasion by nonnative coldwater fishes. Historically, this has involved brook trout that thrive in small, high elevation streams and brown trout or rainbow trout that become established in moderate elevation, midsize streams. All three of these species have detrimental effects on native cutthroat trout in western U.S. streams either through competition, predation, or in the case of rainbow trout, hybridization (Kruse et al. 2001, Novinger and Rahel 2003).

Cluster 3r represents a transition between high elevation mountain watersheds and low elevation, prairie watersheds. These are areas where water development activities are extensive and thus streamflows often are altered. Because these watersheds span a large elevation range, stream gradients tend to be high (table 2.3) suggesting that sediments would generally be moved through these systems. However, sediments would accumulate in the 30% of Cluster 3r reaches that are low gradient. Streams in Cluster 3r watersheds are likely to represent a transition from mainly coldwater fishes in upper elevations to a mixture of coldwater and warmwater fishes at lower elevations. Warming of streams due to loss of forest canopy or global climate change would enhance total fish production and could have negative consequences for coldwater species at the lower elevation portions of these drainages. Cluster 3r watersheds have a largely non-calcareous geology that would produce low nutrient levels in water bodies. Hence aquatic systems in these watersheds would be more affected by nutrient additions than Cluster 5r watersheds, which are characterized by a calcareous geology. Fish assemblages in Cluster 3r watersheds would be susceptible to invasion by nonnative coldwater fishes. Historically, this has involved brook trout that thrive in small, high elevation streams and brown trout or rainbow trout that become established in moderate elevation, midsize streams. All three of these species have detrimental effects on native cutthroat trout in western U.S. streams either through competition, predation, or in the case of rainbow trout, hybridization (Kruse et al. 2001, Novinger and Rahel 2003).

Cluster 4r watersheds are at the highest elevations in areas of calcareous geology and have high gradient streams (fig. 2.17; table 2.3). They are similar to Cluster 1r but have a greater proportion of calcareous geology. Because these are headwater watersheds, most streams will be small and strongly influenced by snowmelt flow regimes. The small size of most streams means they are sensitive to reductions in streamflow associated with water diversion activities. Streams in these watersheds are coldwater systems and may even be too cold to support fish in some cases (Mullner 2001). Warming of streams due to loss of forest canopy or global climate change would not be sufficient to cause the loss of coldwater fishes and might allow populations of these species to expand to higher elevations. Areas with calcareous geology within Cluster 4r watersheds would produce less sediment than areas with non-calcareous geology. Increased sediments would likely be moved through the systems because of the high stream gradients but would accumulate in the few stream reaches that are low gradient. These typically are mountain meadow environments that support high abundances of fish. Nutrient additions would have more impact in watersheds with non-calcareous geology because such rocks typically produce low nutrient conditions in streams. Fish assemblages in Cluster 4r watersheds would be susceptible to invasion by nonnative coldwater fishes. Historically, this has involved brook trout that thrive in small, high elevation streams in the western U.S. and often displace native cutthroat trout (Novinger and Rahel 2003).

Cluster 5r represents a transition between high elevation mountain watersheds and low elevation, prairie watersheds (fig. 2.17). These are areas where water development activities are extensive and thus stream flows often are altered. Because these watersheds span a large elevation range, stream gradients tend to be high (table 2.3) suggesting that sediments would generally be moved through these systems. However, sediments would accumulate in the 20% of Cluster 5r stream reaches that are low gradient. Streams in

Cluster 5r watersheds are likely to represent a transition from mainly coldwater fishes in upper elevations to a mixture of coldwater and warmwater fishes at lower elevations. Warming of streams due to loss of forest canopy or global climate change would enhance total fish production and could have negative consequences for coldwater species at the lower elevation portions of these drainages. Cluster 5r watersheds have a calcareous geology that would produce relatively high nutrient levels in water bodies. Hence aquatic systems in these watersheds would be less affected by nutrient additions than Cluster 3r watersheds, which are characterized by a non-calcareous geology. Fish assemblages in Cluster 5r watersheds would be susceptible to invasion by nonnative coldwater fishes. Historically, this has involved brook trout that thrive in small, high elevation streams and brown trout or rainbow trout that become established in moderate elevation, midsize streams. All three of these species have detrimental effects on native cutthroat trout in western U.S. streams either through competition, predation, or in the case of rainbow trout, hybridization (Kruse et al. 2001; Novinger and Rahel 2003).

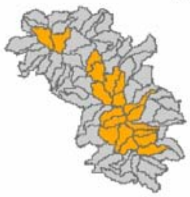
Cluster 6r contains the lowest elevation watersheds on the Bighorn National Forest (fig. 2.17). Streams that originate within these watersheds are likely to have a hydrology strongly influenced by rain events and be susceptible to low flow conditions during summer. Water removal would make exacerbate this situation. Larger streams within these watersheds may contain some coldwater species, in particular, brown trout, which tolerate the warmest temperatures among trout species, present on the Forest. However, the low elevation of these watersheds suggests that any warming of aquatic systems is likely to make them unsuitable for any coldwater fishes. Fish assemblages would be dominated by warmwater, non-game fishes such as native species of minnows and suckers. The high proportion of low gradient stream reaches in Cluster 6r watersheds (40%, table 2.3), means that sediment inputs would not move quickly through these systems. The geology of watersheds in Cluster 6r is mainly non-calcareous, indicating that aquatic systems would be susceptible to eutrophication from nutrient additions. In terms of invasive species, nonnative coldwater fish species are not likely to be of concern because of warm water temperatures. Nonnative warmwater species would mainly be of concern in reservoir habitats because warmwater game species generally do not survive well in small streams subject to intermittency.

Summary of Ecological Driver Analysis at the Management Scale

Table 2.11 shows the 6th level HUBs and their corresponding clusters for the riparian ecosystems. There were six total clusters in this analysis, with Cluster 4r having the least number of 6th level HUBs (3), which were all within the Bighorn National Forest boundary. Cluster 1r had the most 6th level HUBs (19), which were located primarily in the center portion of the Bighorn National Forest.

Table 2.11. Clusters and associated 6th level HUBs for streams/riparian ecosystems identified for the management scale.

Riparian Clusters

	Cluster ID	6th Code HUB IDs
	1	*100800080401, 100800080402, 100800080601, 100800080602, 100800080603 100800100101, 100800100601, 100800160101, 100901010103, 100901010104 100901010201, 100901010202, 100901010203, 100902050101, 100902060101 100902060102, 100902060103, 100902060301, 100902060302*
	2	*100800080404, 100800080405, 100800080605, 100901010102, 100902010301 100902050106, 100902050107*
	3	*100800100102, 100901010105, 100901010109, 100901010206, 100902050102 100902050103, 100902060104, 100902060107, 100902060201, 100902060202 100902060303*
	4	*100800100103, 100800100107, 100901010101*
	5	*100800080403, 100800080406, 100800080502, 100800080604, 100800080606 100800100104, 100800100105, 100800100106, 100800100204, 100800100602 100800100603, 100800100604, 100800160102, 100800160103, 100800160104 100800160107, 100800160108, 100800160301*
	6	*100800100203, 100800100305, 100800100307, 100800100309, 100800100401 100800100402, 100800160109, 100901010106, 100901010107, 100901010110 100901010204, 100901010205, 100901010207, 100901010209, 100902060304 100902060305*

Ecological Driver Analysis for Wetlands

Geology, climate (precipitation regime), and glaciation were drivers chosen to analyze the influence of physical variables on wetlands, including fens, marshes, and wet meadows, which do not occur on floodplains and are not influenced by the hydrologic, geomorphic, and ecological processes of streams in the Big Horn Mountains.

Agglomerative cluster analysis was used to identify groups of HUBs that have a similar percent of their area with certain driver combinations. These cluster groupings were then compared. Once a level of similarity was identified, further explanation of the individual cluster components and characteristics proceeded.

The drivers for wetlands were analyzed at two scales:

1. LANDSCAPE: All 248 6th level HUBs within the seven 4th level HUBs that intersect the Bighorn National Forest; and

2. MANAGEMENT: The 74 6th level HUBs that intersect the Forest boundary.

Landscape Scale

Wetland Cluster Analysis

Landscape-scale agglomerative cluster analysis divided the 248 6th level HUBs into seven clusters based on a 30% similarity cut point (fig. 2.18). There is a distinct break between Clusters 1-5w and 6-7w, due to a major shift in ecological conditions between the mountains and plains regions of the assessment area. The dominance of rain precipitation and non-glaciated valleys is the primary reason for this divergence from the other clusters. This break is also apparent when viewing the map of these clusters (fig. 2.19). These results suggest that the ecological characteristics associated with the Bighorn National Forest are more variable and diverse than the surrounding landscape.

Driver Composition of Individual Wetland Clusters

Table 2.12 shows the percentages of individual drivers from the cluster analysis for wetlands using precipitation, geology, and glaciation drivers. Geology characteristics (e.g., Ca and Cn) are fairly evenly distributed, with three clusters dominated by calcareous geology, and four clusters dominated by non-calcareous geology. The four clusters (1w, 4-6w) dominated with non-calcareous geology, account for 68% of the total area of the landscape. Of the three clusters dominated by calcareous geology, only Cluster 3w is almost entirely located within the Bighorn National Forest (fig. 2.19).

Glaciation occurred at elevations above 6,500 feet in the Big Horn Mountains and constitutes a small portion of the landscape area (Darton 1906). Because of the small amount of the landscape above this elevation, glaciated valleys (Qg) dominate only one of the clusters in this analysis (Cluster 4w). This cluster is located almost exclusively within the Bighorn National Forest boundary (fig. 2.19), and comprises only 6% of the total landscape area. Glaciated valleys are rare in the Bighorn National Forest, so management actions should consider the rarity of this landform, and the habitat needs of the species using these areas.

Three clusters (Clusters 3-5w) are dominated by snowmelt hydrology (Ps) and are the dominant clusters within the Bighorn National Forest boundary (table 2.12, and fig. 2.20). These clusters are associated with the higher elevations of the Big Horn Mountains, and occupy 17% of the entire landscape.

Two clusters (Clusters 1-2w) are dominated by rain-and-snow hydrology (Prs). These clusters are found primarily at the lower elevations of the Big Horn Mountains and comprise 28% of the landscape area (fig. 2.19). Rain-driven hydrology dominated Clusters 6-7w, which were found primarily on the plains. These two clusters comprise 55% of the total landscape-scale area.

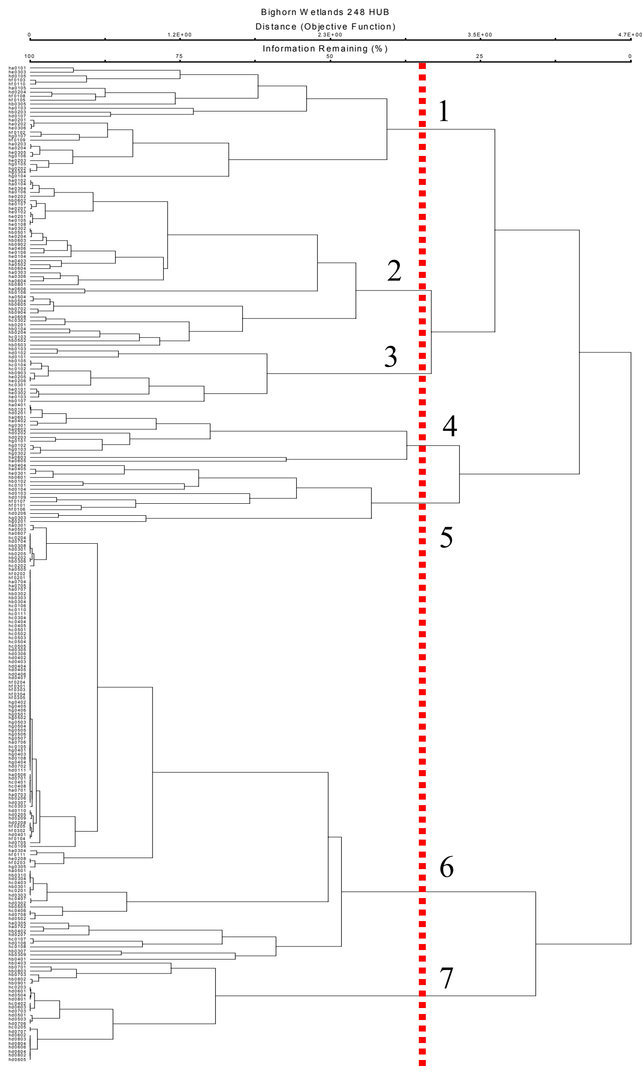


Figure 2.18. Landscape-scale agglomerative cluster analysis of wetland ecosystems using the 248 6th level HUBs in the Bighorn assessment area. Geology, glaciation, and climate (precipitation) drivers produced seven distinct clusters. The dashed vertical line indicates the level of similarity or cut point used to define the clusters, and the numbers next to the line denote the clusters.

Table 2.12. Percent area covered by individual ecological drivers for the landscape-scale wetland assessment of 248 6th level HUBS in the Bighorn National Forest assessment area.

	Percent Area Encompassed by a Specific Ecological Driver						
Wetland	**Geology**		**Glaciation**		**Climate (precipitation)**		
Clusters	**Ca**	**Cn**	**Qg**	**Qn**	**Ps**	**Prs**	**Pr**
1w	21.93	**78.07**	0.21	**99.79**	8.57	**68.53**	22.90
2w	**87.22**	12.78	0.87	**99.13**	11.23	**70.11**	18.67
3w	**88.87**	11.13	0.13	**99.87**	**64.59**	33.51	1.90
4w	9.09	**90.91**	**64.64**	35.36	**89.74**	10.22	0.04
5w	29.99	**70.01**	5.71	**94.29**	**71.78**	28.13	0.09
6w	10.50	**89.50**	0.00	**100.00**	0.78	4.98	**94.23**
7w	**85.58**	14.42	0.00	**100.00**	0.20	6.41	**93.38**

Ca *– calcareous geology,* ***Cn*** *- non-calcareous geology;* ***Qg*** *- glaciated valleys,* ***Qn*** *- non-glaciated valleys;* ***Ps*** *- snowmelt driven hydrology,* ***Prs*** *– rain-and-snow driven hydrology,* ***Pr*** *- rain driven hydrology.*

Ecological Importance of Wetland Clusters at the Landscape Scale

HUBs in Clusters 3-5w occur primarily within the Bighorn National Forest, while Clusters 1w, 2w, 6w, and 7w occur primarily at lower elevation outside the Forest boundary. The lower elevation HUBs will support primarily wet meadows, and wooded riparian vegetation along intermittent and perennial streams. Clusters 3-5w have snow-dominated precipitation regimes, occur at high elevations, and have much greater total wetland area including the vast majority of fens occurring at this scale. Nearly two-thirds of the HUB area in Cluster 4w was glaciated, the HUBs have primarily non-calcareous rocks, and support large wetland complexes in the u-shaped valley bottoms, a large number of fens, and most kettle basin marshes, ponds and lakes. Clusters 6w and 7w have rain-driven precipitation regimes and occur below the limits reached by Pleistocene glaciers. Cluster 6w is dominated by non-calcareous geology, while Cluster 7w is dominated by calcareous bedrock, although this likely has little influence on the wetlands occurring on the plains, where evapotranspiration rates are high, and salts accumulate in meadows, marshes, and salt flats.

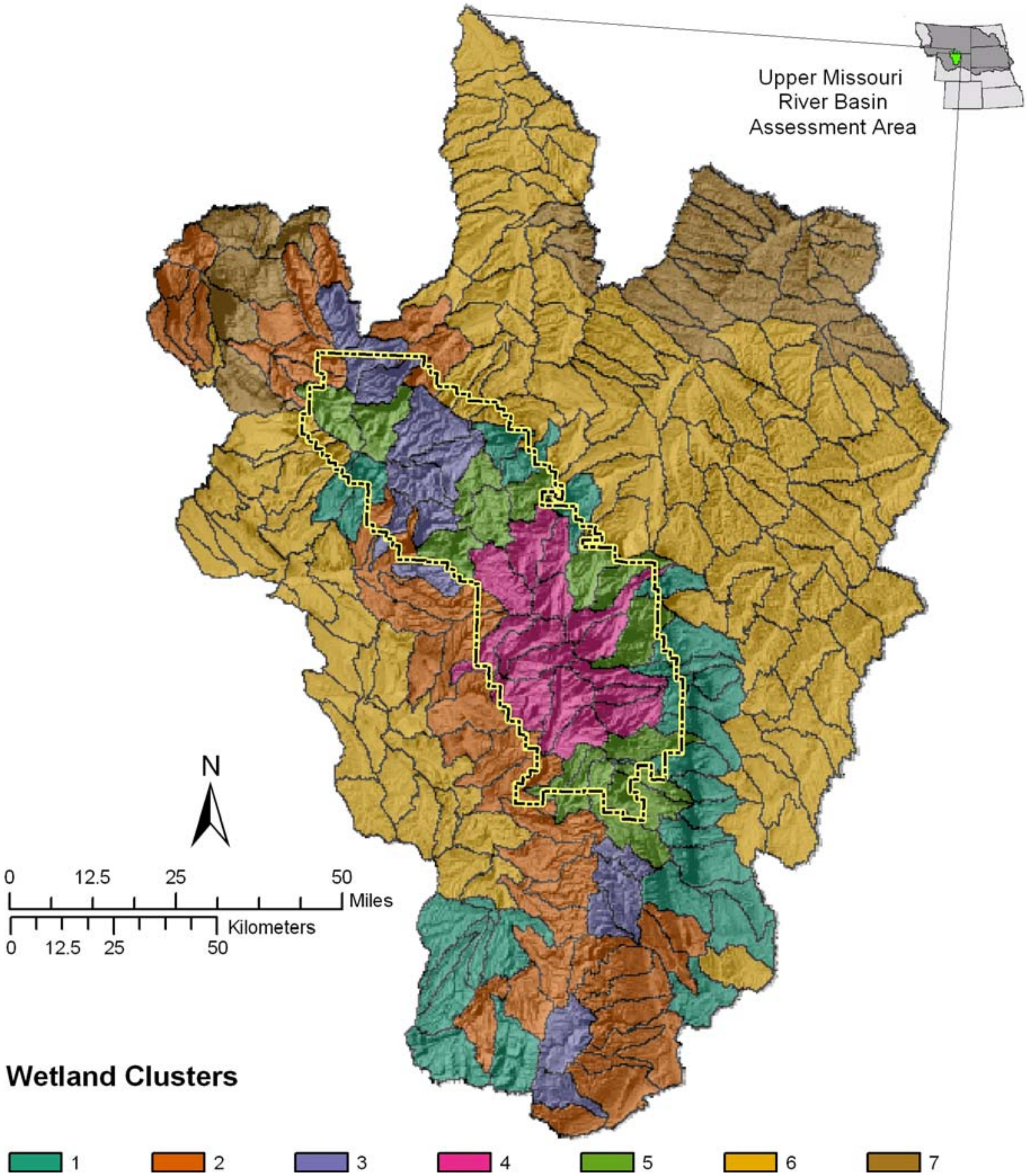


Figure 2.19. Distribution of seven cluster groups for wetland ecosystems based on landscape-scale analysis of ecological drivers for 248 6th level HUBs in the Bighorn assessment area. Geology, climate, and glaciation were the drivers used to produce the clusters.

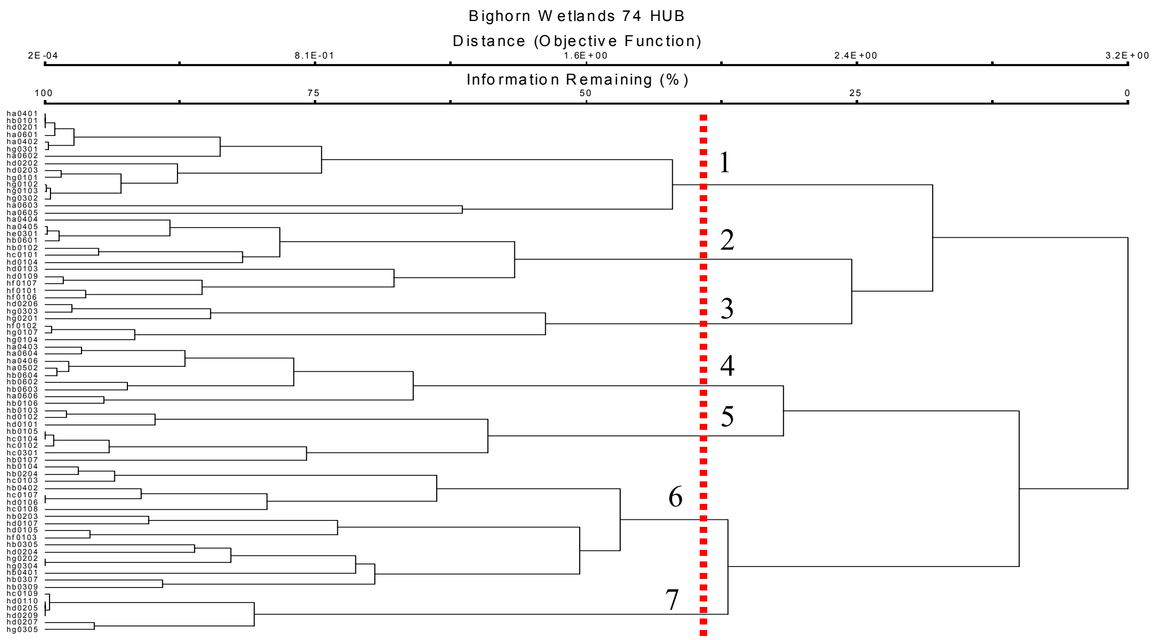


Figure 2.20. Management-scale agglomerative cluster analysis of wetland ecosystems using the 74 6th level HUBs that intersect the Bighorn National Forest. Geology, glaciation, and climate (precipitation) drivers produced seven distinct clusters. The dashed vertical line indicates the level of similarity or cut point used to define the clusters, and the numbers next to the line denote the clusters.

Management Scale

Wetland Cluster Analysis

Management-scale agglomerative cluster analysis divided the 74 6th level HUBS intersecting the Bighorn National Forest into seven clusters for the wetland analysis (fig. 2.20 and table 2.16). The 6th level HUBs that dominate the plains region are not being used for this analysis. As a result, there is no distinct separation between the cluster groups. In effect, this analysis has primarily removed the rain-driven hydrology driver of the analysis, and therefore reinforces the suggestion that this component of the previous analysis for the 248 HUBs was responsible for the large separation seen between Clusters 1-5w and Clusters 6-7w.

Driver Composition of Individual Wetland Clusters

Glaciated valleys (Qg) and rain-driven hydrology (Pr) are primarily restricted to two clusters, Clusters 1w and 7w, respectively (table 2.13). Cluster 1w is located in the high mountains where glacial valleys dominate and the area in Cluster 7w is located at lower elevations where rain dominates the precipitation type (fig. 2.21). The percentage of cluster area dominated by glaciated valleys is small at the landscape scale (approximately 6%) whereas, the analysis at the management scale revealed that Cluster 1w contains most of the glaciated valleys at a much larger proportion in the high mountain areas (19%). This is important because it might be interpreted that the glacial landscape is very abundant when indeed it is restricted to a relatively small area of the Bighorn ecosystem.

Non-calcareous geology (Cn) and non-glaciated valley (Qn) drivers are the most common features in all of the clusters. Snowmelt and rain-and-snow driven hydrology dominate three clusters, although snowmelt driven systems are slightly more dominant. The clusters dominated by calcareous geology are found either at the base of the mountains and barely intersect the Bighorn National Forest boundary (Cluster 4w), or are located in the northern half of the Bighorn National Forest (Cluster 5w). The calcareous geology typical of Clusters 4w and 5w, which accounts for 14% of the total management-scale area, can exert a strong influence on habitat characteristics and hence species distributions.

Table 2.13. Percent area encompassed by individual ecological drivers for the management-scale wetland ecosystem assessment of 74 6th level HUBS intersecting the Bighorn National Forest.

	Percent Area Encompassed by a Specific Ecological Driver						
Wetland	**Geology**		**Glaciation**		**Climate (precipitation)**		
Clusters	**Ca**	**Cn**	**Qg**	**Qn**	**Ps**	**Prs**	**Pr**
1w	9.09	**90.91**	**64.64**	35.36	**89.74**	10.22	0.04
2w	37.41	**62.59**	4.02	**95.98**	**78.22**	21.67	0.11
3w	6.22	**93.78**	8.46	**91.54**	33.29	**61.54**	5.17
4w	**88.29**	11.71	4.08	**95.92**	23.34	**65.45**	11.21
5w	**83.45**	16.55	0.23	**99.77**	**66.65**	30.15	3.20
6w	39.09	**60.91**	0.04	**99.96**	14.55	**44.86**	40.60
7w	7.46	**92.54**	0.00	**100.00**	0.25	16.11	**83.64**

Ca *– calcareous geology,* ***Cn*** *- non-calcareous geology;* ***Qg*** *- glaciated valleys,* ***Qn*** *- non-glaciated valleys;* ***Ps*** *- snowmelt driven hydrology,* ***Prs*** *– rain-and-snow driven hydrology,* ***Pr*** *- rain driven hydrology.*

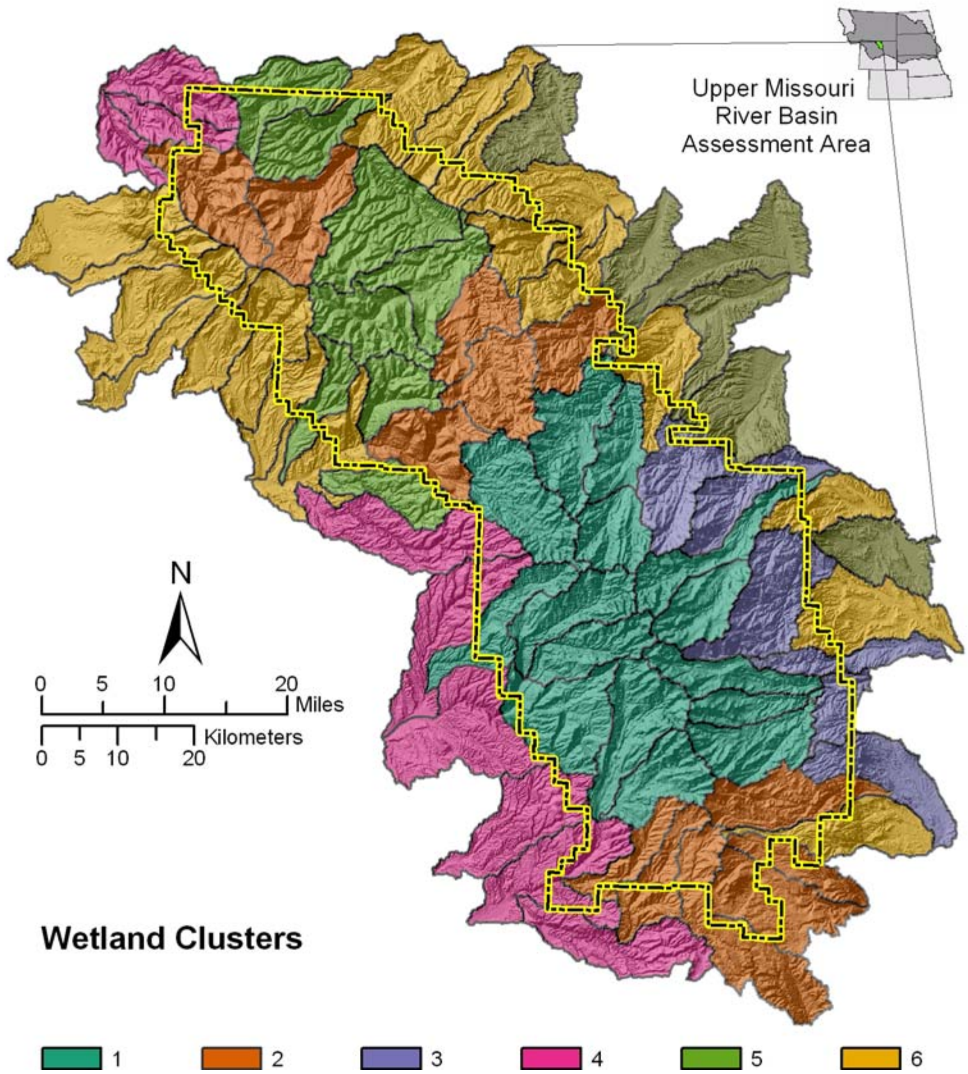


Figure 2.21. Distribution of seven cluster groups for wetland ecosystems based on management-scale analysis of ecological drivers for 74 6th level HUBs intersecting the Bighorn National Forest. Geology, climate, and glaciation were the drivers used to produce the clusters.

Influence of Physical Drivers on Wetland Ecosystems

The proportion of non-calcareous bedrock in HUBs appears positively related to the percentage of wetland ecosystem in each HUB. This suggests that non-calcareous bedrock supports the largest area of suitable landforms for wetland formation, and has sufficient water to support these wetlands. This is because the HUBs with the largest proportion of land area as wetland occur in the high elevation non-calcareous core of the Big Horn Mountains. This area receives the highest precipitation of any sites in north-central Wyoming, and has the largest proportion of glaciated landscapes, both factors that promote wetland formation.

A strong positive linear relationship exists between the proportion of each HUB that was glaciated and the area of lakes and ponds within that HUB (fig. 2.22), indicating that lakes and ponds are strongly tied to glaciated landscapes, which occur primarily in Cluster 1w. There is also a strong positive non-linear relationship between the proportion of HUBs that were glaciated and the area of meadows in the Big Horn Mountains (fig. 2.23).

Table 2.14. Analysis of wetland types within the seven clusters. % HUB Wetland is the mean area of wetlands, % HUB Meadow is the mean percentage of HUBs that are meadows, % HUB Wet+Mead is the mean percentage of HUBs that are wetlands plus meadows, % HUB Pond is the mean percentage of HUBs that are ponds, % HUB Lake is the mean percentage of HUBs that are lakes, % HUB W+M+P+L is the mean percentage of HUBs that are non-streamside riparian. Numbers bolded are the highest values in each category.

Wetland Clusters	% HUB Wetland	% HUB Meadow	% HUB Wet+Mead	% HUB Pond	% HUB Lake	%HUB W+M+P+L
1w	1.35	**0.66**	**2.02**	**0.17**	**1.44**	**3.62**
2w	**2.05**	0.11	**2.16**	0.01	0.02	2.20
3w	0.93	0.13	1.05	0.02	0.03	1.10
4w	0.52	0.04	0.56	0.00	0.00	0.57
5w	1.07	**0.46**	1.52	0.02	0.00	1.54
6w	1.69	0.01	1.70	0.00	0.00	1.70
7w	1.50	0.00	1.50	0.00	0.00	1.50

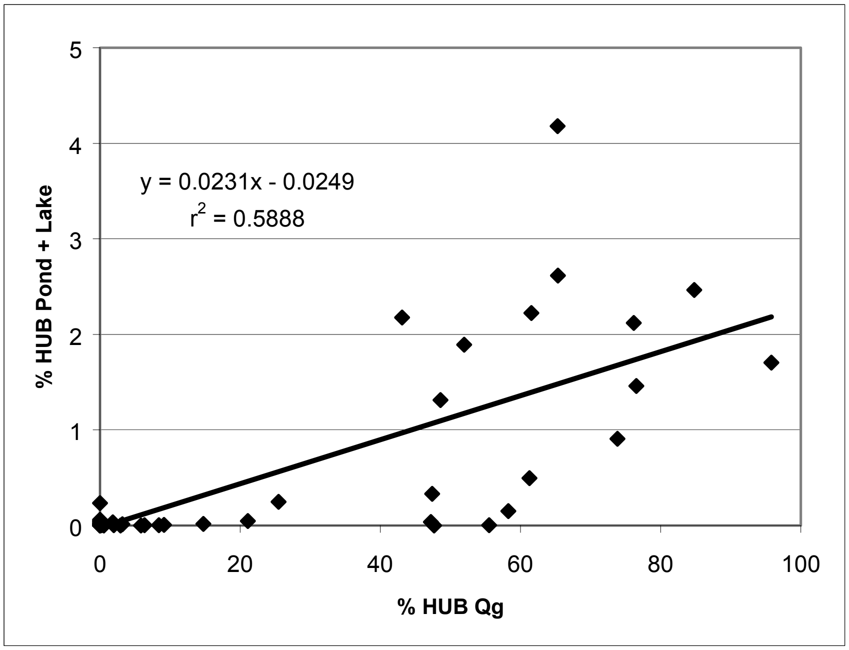


Figure 2.22. Percentage of HUB with Pond or Lake as a function of percentage of HUB that was glaciated (Qg).

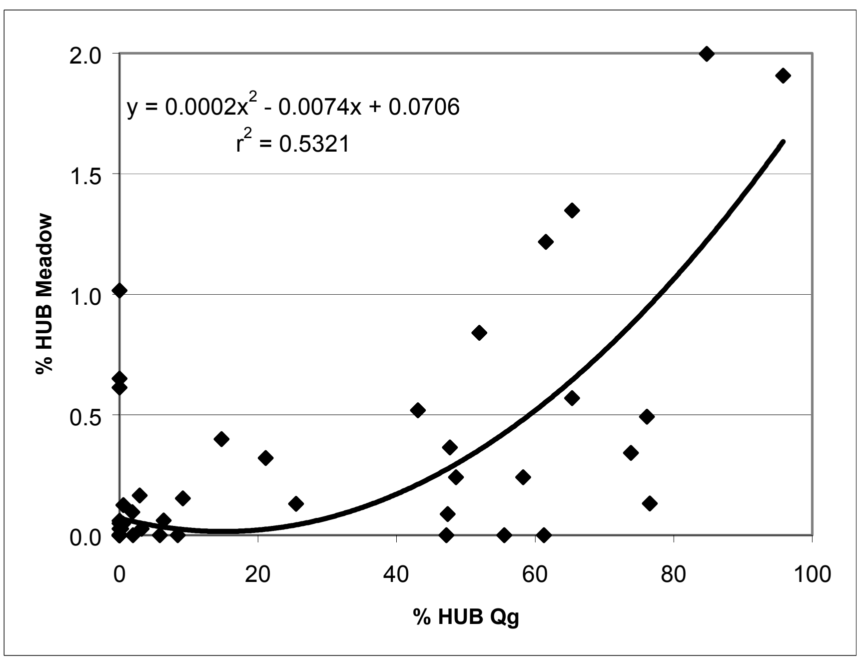


Figure 2.23. Percentage of HUB with Meadow as a function of percentage of HUB that was glaciated (Qg).

Ecological Importance of Wetland Clusters at the Management Scale

The seven clusters identified by the management-scale cluster analysis of the wetland ecosystems in the Bighorn National Forest were quite distinct.

Cluster 1w is most distinct, having glaciated valleys, unglaciated ridges, non-calcareous bedrock, and a snow-driven precipitation regime. This cluster group supports 41% of all the wetland and riparian areas within the Forest even though its HUBs occupy only 33% of the Forest area. While 8.9% of the entire area of the Bighorn National Forest area is mapped as wetland and riparian area, more than 11% of the HUB area in Cluster 1w is wetland and riparian, and HUBs in this cluster contain the largest proportion of meadows (grou8dwater-fed wetlands in drainages), ponds and lakes (table 2.14). These HUBs will be most sensitive to management activities that change the hydrologic or sediment regime of these wetlands.

Cluster 2w occupies high elevation and non-calcareous portions of the Big Horn Mountains, but the HUB headwaters were not high enough to have supported Pleistocene glaciers. More than 10% of its area is mapped as wetland, and HUBs in this cluster support the largest proportion of groundwater-fed wetlands, including springs, seeps, and headwater basins (table 2.14). Because of this, changes in groundwater flow systems will have the greatest impact on wetlands in these HUBs.

Cluster 3w is comprised of six mid-elevation HUBs on the southeastern slope of the Big Horn Mountains. These watershed are largely non-calcareous, unglaciated, and have a rain-and-snow driven precipitation regime. Only 1.1% of the areas in these HUBs is wetland, indicating that groundwater-driven ecosystems are rare.

Cluster 4w occupies most of the southwestern side of the range, has calcareous bedrock, unglaciated watersheds, and a rain-and-snow driven precipitation regime. A very small proportion of each HUB occurs within the National Forest boundary. HUBs in this cluster have the smallest area of wetland, 0.5%, of any cluster in the assessment area. Each HUB supports a very small proportion of wetlands.

Cluster 5w occupies the north central portion of the Big Horn Mountains, has primarily calcareous bedrock, was not glaciated, and has a snow-driven precipitation regime. Portions of these HUBs have relatively low gradient and broad valleys, with the second highest proportion of lakes and meadows of any cluster. This suggests a localized abundance of groundwater-fed wetlands, and ponding water in low gradient valleys. Because of the localized abundance of groundwater driven wetlands and ponds, areas with high wetland concentrations would be highly sensitive to hydrologic changes as well as erosion in the uplands that increases mineral sediment influxes into these wetlands.

Cluster 6w HUBs have both non-calcareous and calcareous bedrock, were not glaciated, occur at low elevation, and have rain and rain-and-snow precipitation regimes. Although the wetland area within this group of HUBs is not high, they are largely as wetland, which are groundwater driven. Thus they are sensitive to changes that influence groundwater flow to the wetlands, as well as increases in mineral sediment influx.

Cluster 7w HUBs are at low elevation have non-calcareous geology, were not glaciated, and rain-driven precipitation regimes. They also tend to be located on the eastern front of the Big Horn Mountains. A relatively small portion of each HUB is within the Forest boundary. The areas within the Forest have very low total wetland area, at only 1.5% of HUBs.

Context to Management Including Sensitivity

Wetland areas occur in sites with seasonally or permanently high water tables, as well as on the margins of ponds and lakes. The water-table depth varies little on an annual basis in fens, while it may vary by many decimeters in meadows and other wetland types. Fens are most sensitive to water-table changes, and water-table drawdowns of as little as 10-20 cm can affect fens such that they lose, rather than gain, organic matter. (Chimner and Cooper 2003). Meadows and wetlands are also easily dewatered, which can convert them to uplands or facilitate exotic plant invasion. Dewatering can also promote pocket gopher invasion of formerly saturated soils, which can destroy soil structure and organic matter content, and change floristic composition by selective herbivory.

Fens are sensitive to changes in thermal regime. For example, compaction reduces snow's insulation capacity and allows soils to freeze, which may disturb fens. In contrast, soils in undisturbed fens rarely freeze in winter. Fens are extremely sensitive to mineral sediment deposition, which results primarily from hill slope erosion. Meadows and other wetlands are also sensitive to mineral sediment deposition, but less so than fens. Changes in nutrient fluxes or turnover within fens can lead to changes in species distribution and community composition. Exotic plants are a threat only in middle and low elevation wetlands, particularly grasses introduced from Europe for "hay", such as timothy (*Phleum commutatum*) and bromegrass (*Bromopsis inermis*) (table 2.15).

Table 2.15. Relative sensitivity of wetland clusters at the management scale to changes in hydrologic and thermal regime, sediment and nutrient input, and to nonnative biota. The sensitivity scale ranges from completely insensitive or not applicable (0) to very sensitive (***).

Wetland Clusters	Hydrology	Thermal	Sediment	Nutrient	Biota
1w	***	***	***	***	*
2w	***	0	**	***	**
3w	**	0	**	*	*
4w	*	0	*	*	*
5w	***	0	**	***	***
6w	**	0	**	***	***
7w	*	0	**	*	***
Hydrology: Reduced groundwater flow, ditching, diversions would reduce fens, meadows and wetlands. Most critical in high elevation watersheds with large ground water flow systems. Lowest threat in HUBs with small areas of meadows and wetlands.					
Thermal: Increased temperatures may influence the carbon budgets of fens, by increasing ecosystem productivity, or decomposition rates.					
Sediment: Decreased sediment flux from dams may lead to down cutting and floodplain erosion, increased sedimentation from hill slopes.					
Nutrients: Nutrients deposited in wetlands from hillslope sediment or groundwater are most damaging to fens, meadows, and wetlands.					
Biota: Exotic plants are most prevalent at lower elevations, and are relatively unimportant in higher elevation HUBs. Woody plants are most problematic in drainages, while exotic grasses are most problematic in mid elevation meadows and wetlands.					

Table 2.16. Clusters and associated 6th level HUBs for wetlands identified for the management scale.

Wetland Clusters

	Cluster ID	6th Code HUB IDs
	1	*100800080401, 100800080402, 100800080601, 100800080602, 100800080603 100800080605, 100800100101, 100901010201, 100901010202, 100901010203 100902060101, 100902060102, 100902060103, 100902060301, 100902060302*
	2	*100800080404, 100800080405, 100800100102, 100800100601, 100800160101 100901010103, 100901010104, 100901010109, 100902010301, 100902050101 100902050106, 100902050107*
	3	*100901010206, 100902050102, 100902060104, 100902060107, 100902060201 100902060303*
	4	*100800080403, 100800080406, 100800080502, 100800080604, 100800080606 100800100106, 100800100602, 100800100603, 100800100604*
	5	*100800100103, 100800100105, 100800100107, 100800160102, 100800160104 100800160301, 100901010101, 100901010102*
	6	*100800100104, 100800100203, 100800100204, 100800100305, 100800100307 100800100309, 100800100401, 100800100402, 100800160103, 100800160107 100800160108, 100901010105, 100901010106, 100901010107, 100901010204 100902050103, 100902060202, 100902060304*
	7	*100800160109, 100901010110, 100901010205, 100901010207, 100901010209 100902060305*

Riparian and Wetland Types of the Big Horn Mountains

Girard et al. (1997) identified 53 types of riparian and wetland communities in the Bighorn National Forest (table 2.17). They divided communities into ecological types and community types. Ecological types represented the potential natural vegetation, while community types represented seral vegetation. Table 2.17 summarizes the number of community types for each of the major plant species or plant physiognomic group in the Big Horn Mountains.

Community types dominated by Geyer willow (*Salix geyeriana*), narrowleaf cottonwood (*Populus angustifolia*), and water birch (*Betula fontinalis*) are found primarily on floodplains of medium to larger streams at mid to lower elevations. Communities dominated by Booth (*Salix boothii*), Planeleaf (*S. planifolia*), Wolf (*S. wolfii*), and Bebb (*S. bebbiana*) willows are typically found on groundwater influenced sites, although these may be adjacent to or on floodplains. Communities dominated by sedges (primarily *Carex utriculata* and *C. aquatilis*), grasses (primarily *Deschampsia cespitosa* and *Calamagrostis canadensis*), shrubby cinquefoil (*Pentaphylloides floribunda*), quaking aspen (*Populus tremuloides*), lodgepole pine (*Pinus contorta*), and Engelmann spruce (*Picea engelmannii*) are wet meadows and fens fed primarily by groundwater. Thus, eight total communities occur primarily at mid to lower elevations in the foothills, whereas 45 are found at mid to high elevations in the mountains. Stream-influenced riparian communities are typically located on floodplains (e.g., 12 of the total 53 communities). The other 41 communities (77% of the total) occur in locations either adjacent to or isolated from streams, but do not owe their origin or support to the hydrologic and geomorphic processes driven by stream flows, and are supported by groundwater flow systems originating on hill slopes and small watersheds recharged by rain and snowmelt.

Table 2.17. Number of riparian and wetland communities in the Bighorn National Forest based on dominant plant group (Girard et al. 1997).

Community Type Based on Dominant Seral Vegetation	Number of Communities
Sedge	7
Grass	4
Booth Willow	6
Geyer Willow	3
Planeleaf Willow	8
Wolf Willow	5
Other Willow	4
Shrubby Cinquefoil	2
Narrowleaf Cottonwood	4
Quaking Aspen	2
Lodgepole Pine	3
Engelmann Spruce	5
Total	53

Comparison of Forest Service and National Wetlands Inventory Mapping

The US Forest Service (USFS) and US Fish and Wildlife Service's National Wetlands Inventory (NWI) have independently mapped wetlands in the Big Horn Mountains. The USFS mapped wetlands for the entire Bighorn National Forest, while the NWI mapping for the Big Horn Mountains region is incomplete. Thus, a comparison of the acreage of wetland mapped by these two efforts is not possible across the entire Forest, but it is possible for a few areas where the two mapping efforts overlapped (fig. 2.24).

There are significant differences in the area of wetlands mapped by the USFS and NWI, but the bias was not consistent by agency. Figure 2.25 shows a high elevation portion of HUB #100901010203 with USFS and NWI coverage overlain. The NWI identified 574.21 hectares of wetland, while the USFS identified nearly triple that amount (1522.78 hectares; table 2.18). The comparison of low elevation wetlands on HUB #100901010105 indicated even larger discrepancies, with the NWI identifying 45.31 hectares and the USFS identifying 497.91, more than 10 times more (fig. 2.26).

Field validation of wetlands delineations in the Bighorn National Forest identified potential reasons for the discrepancy between USFS and NWI mapping. For example, the USFS overestimated the area of wetlands by including large areas of meadows that likely are not wetlands. In contrast, the NWI missed many wetlands, and in particular did not include connections between many wetlands and wetland complexes as can be seen on Figures 2.25 and 2.26. The unique classification system used by the USFS in the Bighorn National Forest, and their classification units such as streams, wetlands, meadows, and ponds and lakes makes it hard to compare with a national classification system such as the Cowardin et al. (1979) classification system. In addition, the USFS classification and mapping contains a number of assumptions that make some aspects of the mapping tentative and in need of additional field verification (M. Girard, oral commun. 2002). For example, some dry meadows occurring adjacent to incised streams were assumed to have been wet meadows prior to stream incision, which was presumably caused by cattle grazing. Thus, large dry meadow areas are mapped as wetland or wet meadow. The most problematic issue with the two mapping efforts are concerns over where omitting stream connections are omitted. When stream connections are missed, wetlands may be incorrectly classified as "isolated" when they are not (e.g., NWI). In addition, the Forest Service mapped many dry meadows as wetlands. Isolated wetlands have limited federal protection under the Clean Water Act.

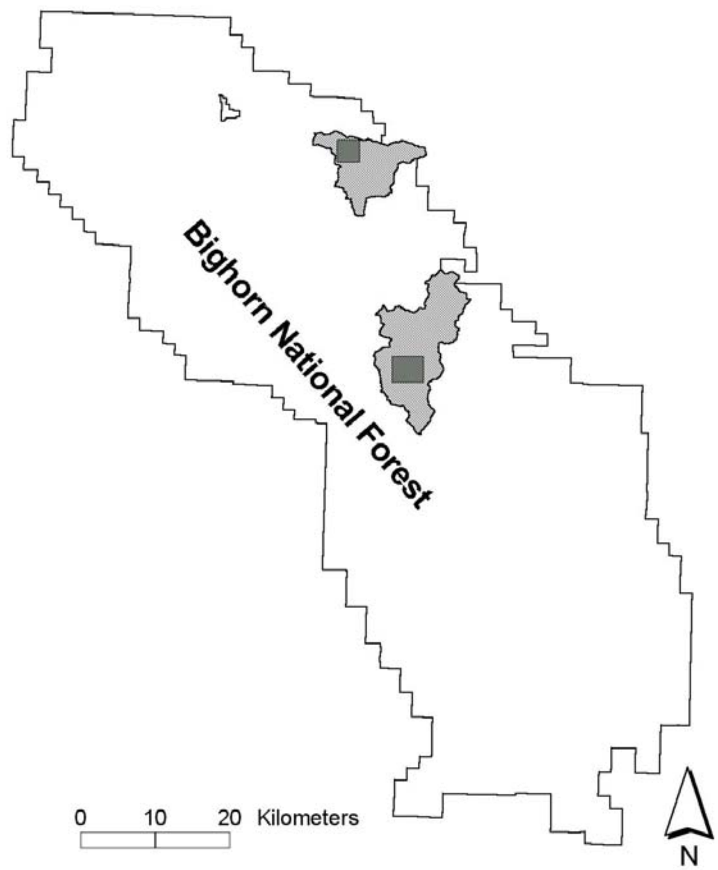


Figure 2.24. Location of high (bottom = HUB #100901010203) and low elevation HUBs (top = HUB #100901010105) areas with both USFS and NWI wetland mapping. Gray shading identifies the entire HUB, while the black box identifies the areas compared.

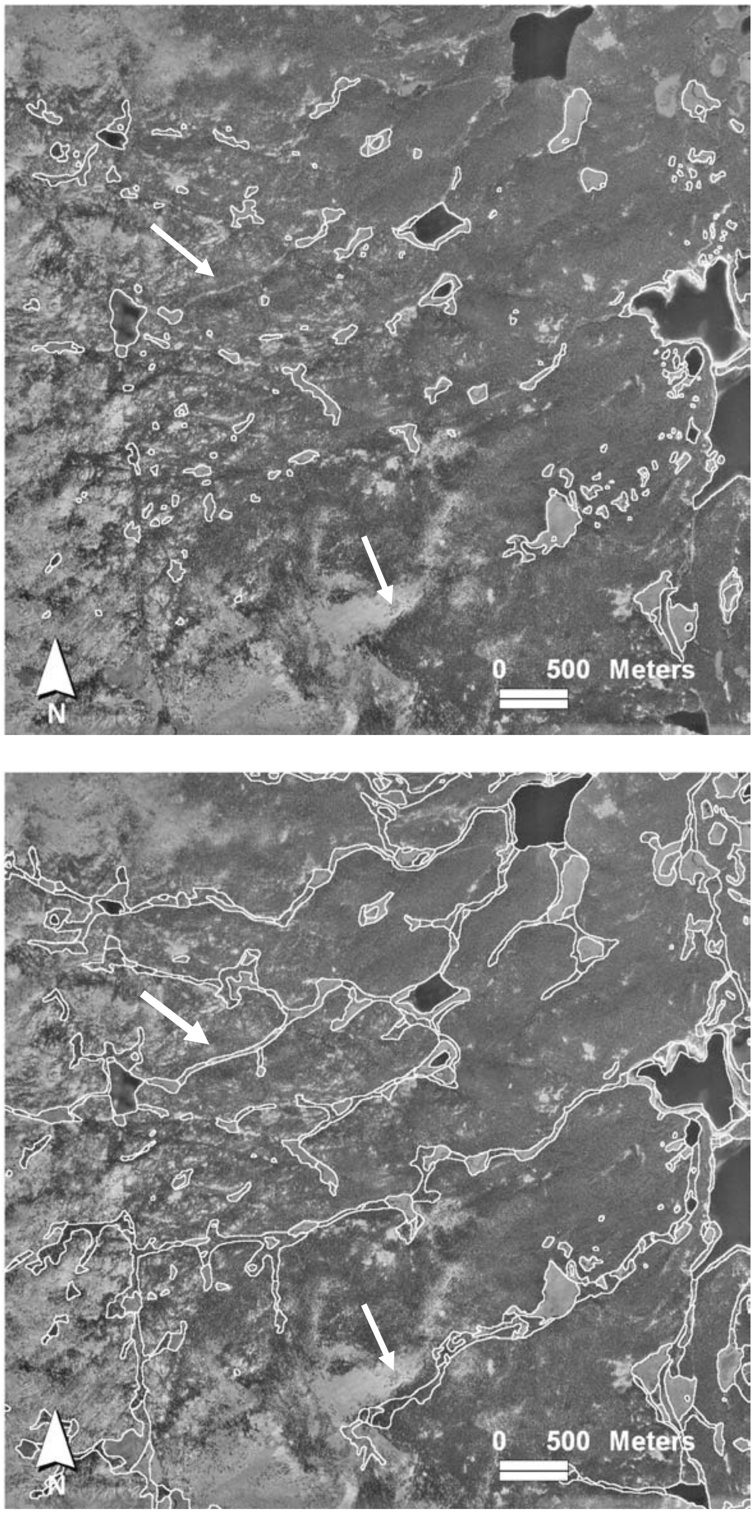


Figure 2.25. Comparison of NWI (top) and USFS (bottom) wetland/riparian mapping for high elevation sites in the Bighorn National Forest. Mapping is overlain onto air photographs in this portion of HUB #100901010203. Arrows are used to compare areas where the differences between the two mapping efforts were striking.

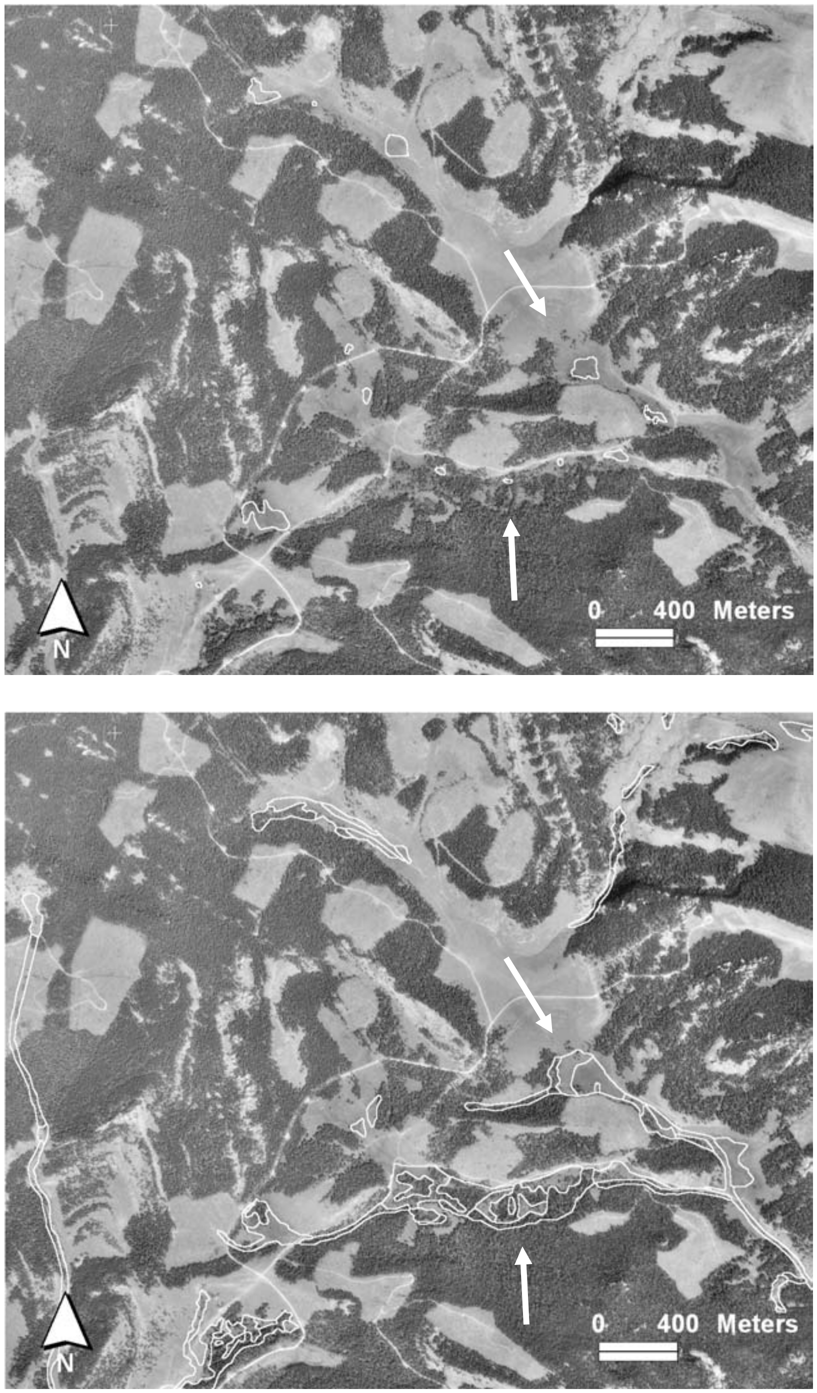


Figure 2.26. Comparison of NWI (top) and USFS (bottom) wetland/riparian mapping for low elevation sites in the Bighorn National Forest. Mapping is overlain onto air photographs in this portion of HUB #100901010105. Arrows are used to compare areas where the differences between the two mapping efforts was striking.

Table 2.18. HUB number, area (hectares), elevation category, and wetland area and percentage of HUB occupied by wetlands as identified by the NWI and USFS mapping for one low and one high elevation HUB in the Bighorn National Forest.

6th Level HUB Code	Area	Elevation	Data Set	Wetland Area	Percentage
100901010105	7,653	low	NWI	45.31	0.6%
			USFS	497.91	6.5%
100901010203	13,757	high	NWI	574.21	4.2%
			USFS	1,522.78	11.1%

Presence of Rare Wetland Plants in the Big Horn Mountains

Twenty-four state and globally rare vascular plant species are known to occur in wetlands of the Big Horn Mountains (table 2.19). These data were obtained from the University of Wyoming Herbarium database. Some of these species, including *Carex limosa*, *Eriophorum chamissonis* (fig. 2.27), and *Cypripedium calceolus* are widespread in the Holarctic, but occur in the Bighorn area widely disjunct from the main species range in boreal regions. These species are not endangered globally, but the Bighorn populations have been isolated from the main species range for thousands, if not tens of thousands of years and where local extinction occurs, repopulation is not possible (Weber 1965; Cooper 1996; Cooper et al. 2002). Many of these species occur in only one wetland, so their fate depends upon the persistence of the hydrologic, geochemical, and geomorphic conditions that each species has survived under for thousands of years.

Many rare plant species also occur along the eastern foothills of the Big Horns and the crest of the range (fig 2.28). Many rare species occur in fens, including *Carex limosa*, *Eriophorum chamissonis*, and *Pedicularis parryi*. Other species occur in foothill riparian zones such as *Celtis occidentalis*, while others occur in wet meadows, including *Cypripedium calceolus* and O*trychium minganense*, or plains marshes such as *Sparganium eurycarpum* and *Schoenoplectus heterochaetus*. Thus, the presence of rare wetland plants is likely to be highest in HUBs with abundant fens, wet meadows, and some cool north-facing foothills canyons.

Figure 2.27. Distribution of *Eriophorum chamissonis* in the northern hemisphere. The most southerly populations of this species in the world occur disjunct from the main boreal populations in fens within Wyoming and Colorado, including the Bighorn National Forest. (Map from: Hultén, E. 1968. Flora of Alaska and Neighboring Territories, a manual of the vascular plants. Stanford University, Press, Stanford, CA, 1008 p.).

Table 2.19. Rare wetland plants of the Big Horn Mountains, Wyoming. Rank refers to rarity globally (G) and in Wyoming (S). NWI indicates the ranking of each species based upon its likelihood of occurrence in wetland (Reed 1988). County is the county in Wyoming.

SCIENTIFIC NAME	Rank	Rank	NWI	County	Longitude	Latitude
1. Adoxa moschatellina	G5	S1	FAC-	Sheridan	-107.4500	44.8736
2. Agoseris lackschewitzii	G4	S3	?	Johnson	-106.9242	44.1939
3. Botrychium minganense	G5T4	S1	FACW	Johnson	-106.9458	44.2578
3. Botrychium minganense	G4	S1	NI	Sheridan	-107.7689	44.9361
4. Botrychium virginianum	G5	S1	FACU	Sheridan	-107.7481	44.9528
5. Carex limosa	G5	S2	OBL	Big Horn	-107.2306	44.1686
6. Carex misandra	G5	S1	FACU	Johnson	-107.0925	44.2142
7. Celtis occidentalis	G5	S1	FAC-	Sheridan	-107.3444	44.8492
8. Cirsium foliosum	G5	S1	NI	Sheridan	-107.5883	44.7606
9. Cypripedium calceolus pubescens	G5	S1S2	FACW-	Sheridan	-107.6486	44.9722
9. Cypripedium calceolus pubescens	G5	S1S2	FACW-	Washakie	-107.3628	44.0658
9. Cypripedium calceolus pubescens	G5	S1S2	FACW-	Sheridan	-107.2378	44.7592
9. Cypripedium calceolus pubescens	G5	S1S2	FACW-	Sheridan	-106.9839	44.6764
10. Cypripedium montanum	G4G5	S1	FACU	Sheridan	-107.2381	44.7592
10. Cypripedium montanum	G4G5	S1	FACU	Sheridan	-107.0297	44.5883
10. Cypripedium montanum	G4G5	S1	FACU	Johnson	-106.9969	44.3031
10. Cypripedium montanum	G4G5	S1	FACU	Sheridan	-106.9333	44.5597
10. Cypripedium montanum	G4G5	S1	FACU	Johnson	-106.8814	44.5317
11. Epipactis gigantea	G4	S1	FACW+	Big Horn	-107.7736	44.5403
12. Equisetum sylvaticum	G5	S1	FACW	Sheridan	-107.2700	44.6122
13. Erigeron humilis	G4	S2	FACW-	Big Horn	-107.2161	44.3894
14. Eriophorum chamissonis	G5	S1S2	OBL	Sheridan	-107.2644	44.6125
15. Juncus triglumis v. triglumis	G5T5	S1	FACW	Johnson	-107.1269	44.2750
16. Listera convallarioides	G5	S1	FACU	Sheridan	-107.2625	44.7611
17. Pedicularis parryi mongollonica	G5T2T	S1	FACU	Big Horn	-107.5319	44.6014
18. Potamogeton amplifolius	G5	S1	OBL	Johnson	-107.0131	44.2694
19. Rorippa calycina	G3	S2S3	FACW	Carbon	-107.0317	41.7458
20. Rubus acaulis	G5	S1	FAC+	Johnson	-106.9969	44.3031
20. Rubus acaulis	G5	S1	FAC+	Johnson	-106.9347	44.2672
21. Schoenoplectus heterochaetus	G5	S1	OBL	Sheridan	-106.0819	44.6958
22. Sparganium eurycarpum	G5	S1	OBL	Sheridan	-106.9778	44.8244
23. Sullivantia hapemanii hapemanii	G3T3	S3	NI	Big Horn	-107.9278	44.9189
24. Utricularia minor	G5	S1S2	OBL	Washakie	-107.2361	44.1661

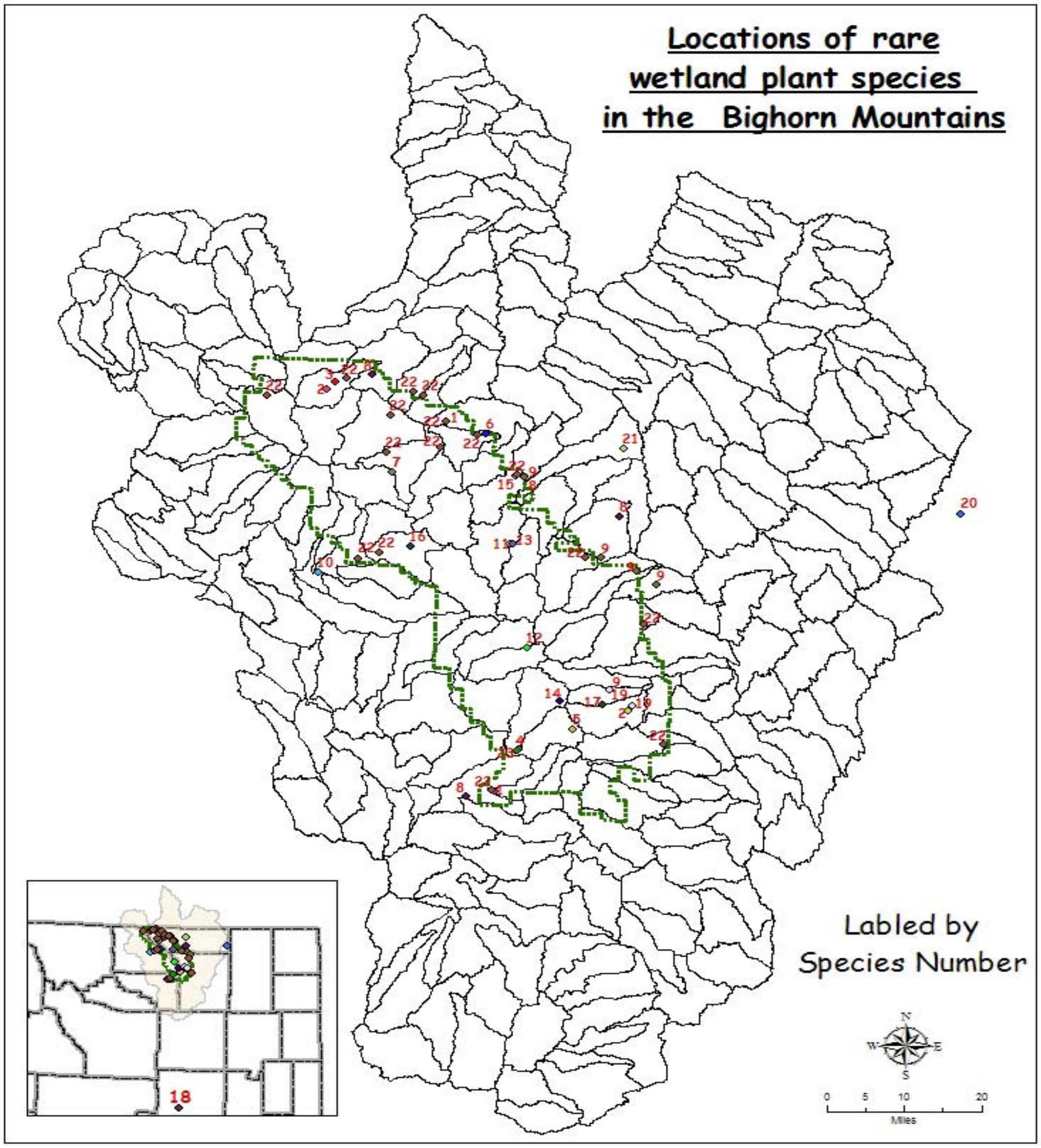


Figure 2.28. Known location of rare wetland plants in the Big Horn Mountain region in north central Wyoming. Data from Wyoming Natural Heritage Database, University of Wyoming. Species numbers are in Table 2.19.

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